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Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192)

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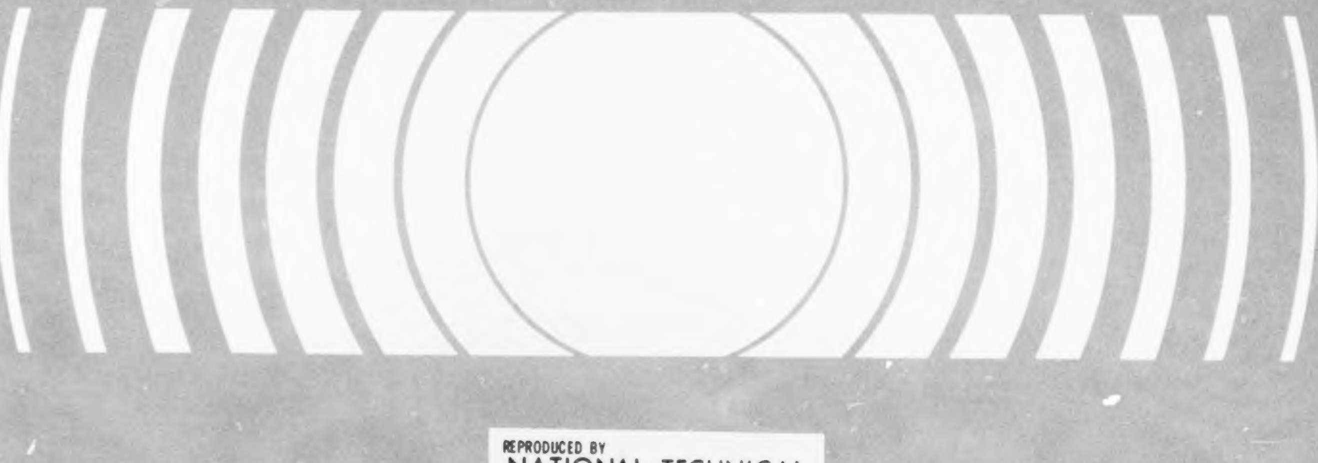
Draft Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192)



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16. ABSTRACT

The Environmental Protection Agency is proposing standards for disposing of uranium mill tailings from inactive processing sites and for cleaning up contaminated open land and buildings. These standards were developed pursuant to the Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604). This Act requires EPA to promulgate standards to protect the environment and public health and safety from radioactive and nonradioactive hazards posed by uranium mill tailings at designated inactive processing sites. The Draft Environmental Impact Statement examines health, technical, cost, and other factors relevant to determining standards. The proposed standards for disposal of the tailings piles cover radon emissions from the tailings to the air, protection of surface and ground water from radioactive and nonradioactive contaminants, and the length of time the disposal system should provide a reasonable expectation of meeting these standards. The proposed cleanup standards limit indoor radon decay product concentrations and gamma radiation levels and the residual radium concentration of contaminated land after cleanup.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites
(40 CFR 192)

December 1980

Office of Radiation Programs
Environmental Protection Agency
Washington, D.C. 20460

FOREWORD

(X) Draft Environmental Statement
( ) Final Environmental Statement

Environmental Protection Agency
Office of Radiation Programs

1. This Environmental Impact Statement was prepared by the Criteria and Standards Division (CSD), Office of Radiation Programs (ORP), U.S. Environmental Protection Agency (EPA).

Questions regarding this statement should be directed to Stanley Lichtman, Project Leader, in care of the Director, Criteria & Standards Division, or at (703) 557-8927.

2. EPA is proposing standards for the disposal of uranium mill tailings from inactive processing sites, and for cleanup of land and buildings contaminated by tailings. EPA developed these standards pursuant to the Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604). The Act requires EPA to set generally applicable standards to protect the public health, safety, and the environment from hazards posed by uranium mill tailings at specific inactive processing sites. The 25 sites initially designated are in Arizona, Colorado, Idaho, New Mexico, North Dakota, Oregon, Pennsylvania, Texas, Utah, and Wyoming.

3. In developing a standard, EPA staff members meet with individuals and organizations to seek both information and a thorough understanding of the issues. The staff then independently assesses the considerations specified in EPA's Regulation EIS Procedures (39 F.R. 37419, October 21, 1974).

4. This evaluation leads to the publication of a Draft Environmental Impact Statement (DEIS), which is circulated to appropriate governmental agencies for comment. For this DEIS, EPA gained considerable information from the Draft Generic Environmental Impact Statement on Uranium Milling (NUREG-0511) prepared by the U.S. Nuclear Regulatory Commission (NRC). EPA has notified the public through the *Federal Register* that the DEIS is available, and has invited interested persons to comment on the draft statement and the proposed standards.

Single copies of this statement may be obtained from:

Director, Criteria and Standards Division
Office of Radiation Programs (ANR-460)
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

5. After considering comments on the Draft EIS, EPA will prepare a Final EIS (FEIS) which will include a discussion of the concerns raised and the conclusions EPA reached. EPA then will release the Final Environmental Impact Statement.

6. EPA has asked the following Federal agencies to comment on this statement:

Advisory Council on Historic Preservation
Department of Agriculture
Department of the Army, Corp of Engineers
Department of Commerce
Department of Energy
Department of Health, Education & Welfare
Department of Housing and Urban Development
Department of the Interior
Department of Justice
Department of Transportation
Federal Energy Regulatory Commission
Nuclear Regulatory Commission

EPA also has sent copies to all State Clearinghouses, to the American Mining Congress and to other individuals and organizations who have notified EPA of their interest.

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SUMMARY

The Environmental Protection Agency (EPA) is proposing standards for disposing of uranium mill tailings from inactive processing sites and for cleaning up contaminated open land and buildings. These standards were developed pursuant to the Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604). This Act requires EPA to promulgate standards that can be generally applied to protect the environment and the public health and safety from radioactive and nonradioactive hazards posed by uranium mill tailings at designated inactive processing sites. The 25 presently designated sites are inactive uranium mill tailings piles in the States of Arizona, Colorado, Idaho, New Mexico, North Dakota, Oregon, Texas, Utah, and Wyoming and at the location of a former rare-metals plant in Pennsylvania.

1. The Proposed Standards Cover Two Situations

a. Disposal of Tailings:

The standards limit release of radon gas to the air from disposed tailings to 2 picocuries per square meter per second (pCi/m^2-sec), about twice the average of normal soils. When the radon from a cover of normal soil is added to that allowed from tailings, the resulting release will still be within a normal range of variation. The standards restrict contamination of drinkable ground water to preserve its potability. Lower quality but potentially useful ground water and all surface waters are protected against degradation. The standards also require a reasonable expectation that the disposal methods will be effective for at least one thousand years.

b. Cleanup of Contaminated Open Land and Buildings:

The standards require cleanup of open land contaminated by tailings when the average radium concentration attributable to tailings exceeds 5 picocuries per gram (pCi/gm). Five pCi/gm is three to five times the average radium concentration in normal U.S. soil. Soil contaminated by tailings, however, usually lies in a thin layer on the surface, while the radium in normal soil occurs throughout its full thickness. Radiation from land that satisfies the standard will be within the normal variations among undisturbed land areas.

2. Summary of Environmental Impacts

EPA estimates that implementing the disposal standards at all designated sites would prevent about 200 premature deaths per century from radiation-induced lung cancer for as long as the standards apply. We further require a reasonable expectation that the standards will be satisfied for at least one thousand years. About 140 of the 200 deaths would be expected in the populations within 50 miles of the inactive tailings piles and the rest in the remaining continental U.S. population. Health effects from contaminated ground water are not included in the above estimate.

Estimates of health improvements from implementing the cleanup standards have not been made. Such benefits would include not only preventing adverse health effects, but also reclaiming contaminated lands currently unfit for unrestricted use.

We have estimated the costs of implementing the standards. For an average inactive uranium mill tailings pile, meeting the disposal standard will cost from 1 million (1978) dollars to over 13 million (1978) dollars, depending on the methods used. In a previous cleanup program for buildings authorized by Congress in 1972 under PL 92-314, cleanup cost about 13,500 (1978) dollars for a residential structure and about 38,500 (1978) dollars for a commercial building. The probable total cost of the cleanup and disposal programs under PL 95-604 will be 200 million (1978) dollars to 300 million (1978) dollars. These expenditures could benefit the local economies, and should have no perceptible effect on the national economy.

3. Alternatives Considered

With regard to the form and content of the standards, we considered the following major alternatives:

a. Disposal Standards:

Uncontrolled uranium mill tailings endanger people and the environment --

- By releasing radon-222, a radioactive gas, into the atmosphere, where it and its radioactive decay products can be breathed;
- By supplying a source of windblown radioactive particles;
- By exposing people who live or work near the tailings to direct gamma radiation; and

- By releasing radioactive and nonradioactive contaminants to surface or ground water through erosion or leaching.

Generally applicable standards to protect the environment and the public's health and safety must be based on the reasonableness and feasibility of controlling these potential hazards. Because of the long lifetimes of the radioactive contaminants and the presence of such permanently toxic nonradioactive contaminants as arsenic and lead in tailings material, the longevity or permanence of control methods must be considered.

The principal health hazard is release of radon-222 into the atmosphere. We conclude that techniques which control radon releases reasonably well and have lasting effectiveness will essentially control airborne particles and direct gamma radiation completely. The standards, therefore, do not specifically address these latter two hazards, and the following discussion of control alternatives is restricted to radon-222 releases and water. This section also discusses alternative longevity requirements for controls.

(1) Radon Control

We considered alternatives for limiting radon that ranged from no control (the existing condition) to essentially complete control (preventing almost all radon release). We also explored middle alternatives to control radon release to various degrees down to about the normal background level. We compared all three alternatives for costs, benefits, feasibility, longevity, and other factors.

We rejected the concept of no control, because people living near uncontrolled piles would clearly have a higher risk of radiation exposure. Radon emissions, moreover, would convey a health hazard over long distances and for long periods.

We rejected the concept of essentially complete radon control, because it may be impractical and would provide a small added reduction in overall risk at relatively high cost.

The proposed disposal standards, therefore, limit radon releases from tailings piles to be within the range of variation found in normal soils.

(2) Water Contamination

Alternatives for limiting water contamination range from no additional control (the existing condition) to complete prevention. We examined these and a middle ground: limiting contamination to a degree comparable to other water quality programs.

We concluded that some control is warranted. The potential effects of uranium mill tailings on surface and ground water quality vary considerably from site to site, and under some conditions ground water could become unusable over an area much larger than the pile. The likelihood that this will happen has not been thoroughly examined.

Available information suggests that special measures to protect ground water often will be unnecessary. Where the standards might be exceeded only immediately near a pile, moreover, we believe that the substantial disruptions and cost needed to avoid the violation would be unwarranted.

We therefore propose to apply ground water standards only within one kilometer from the pile when an existing site is used for disposal, and within 0.1 kilometer at new disposal sites.

The standards provide that tailings disposal will not cause ground water contaminants to exceed specified levels. If the ground water already exceeds these levels for reasons other than tailings, no further degradation is allowed. Where ground water contamination has already occurred, it may sometimes be possible to reduce it, but requiring remedial actions to satisfy pre-set standards in every case is not practical. The proposed ground water standards therefore do not apply to materials already released from the tailings. Using their authorities under PL 95-604, however, we expect other Federal agencies to take practical actions at sites where they are needed to avoid harm from such materials.

The radon release and ground water protection standards should protect surface water adequately. As assurance, however, we propose to require that surface water not be degraded by tailings after disposal of the piles.

(3) Length and effectiveness of controls

The health protection the disposal system ultimately affords depends on the degree of control and the time over which control is maintained. Requirements could range from a few years to as long as the tailings remain potentially hazardous. We considered the technical and economic aspects of various control periods.

Congress recognized that uranium mill tailings represent long-term hazards, and directed EPA to set reasonable standards for their long-term disposal. We propose to require a reasonable expectation that the radon emission and water protection standards for tailings disposal will be satisfied for at least one thousand years. Institutional controls, such as record keeping, maintenance, and land-use restrictions, can provide greater protection than the standards require, but they are unreliable as the primary control over one thousand years. Though institutional controls can be helpful, physical disposal methods are necessary.

Pragmatism suggests the choice of a thousand-year period, though technically and economically reasonable disposal methods may, for some tailings piles, afford even longer protection. A thousand-year standard reflects our judgment that the disposal standards must be practical for all the inactive sites. It does not mean that we care little for the future beyond one thousand years.

b. Cleanup Standards:

Uranium mill tailings from inactive sites have been spread near and far by wind, water, and people. Therefore, standards for cleanup must address the following situations:

- o Tailings have spread different distances from different piles, are found at various depths in the soil, and are mixed with various materials. The standards must therefore specify the quantity or concentration of tailings which requires cleanup.

- o Radioactive elements leach out of tailings piles into the subsoil beneath. The standards must therefore specify the permissible level of radioactivity in the subsoil, should the pile covering it be removed.

- o Tailings used a landfill or made into building materials or which accumulate around a structure are particularly hazardous. The exchange of air between a building's interior and the outdoors is limited, so indoor concentrations of radon decay products may be many times the outdoor levels. The standard must therefore specify the maximum allowable concentration of radon decay products inside buildings. The cleanup standard for open land must consider the possibility of future construction.

The level of radon decay products in a building is related, among other things, to the concentration of radium, present naturally or as a contaminant, in the underlying or adjacent soil. So many other factors arise, however -- the rate at which air is exchanged between indoors and outdoors, for example -- that strictly correlating the interior level with the radium in the soil is difficult. Radium concentrations from 1 to 5 pCi/gm in soil, a range whose lower end is common among natural soils, can produce indoor levels of radon decay products greater than 0.01 WL.

Natural or contaminated soils with radium concentrations of 5 pCi/gm through a depth of several feet can also produce gamma radiation exposure rates of about 80 mR/yr. Exposure rates are proportionately higher or lower for other radium concentrations, decreasing as the layer of radium-containing material becomes thinner or is covered over by other materials.

The proposed standard requires that for any open land contaminated with tailings, the average radium concentration in any five-centimeters-thick layer within one foot of the surface, or any 15 cm layer below one foot, shall not be more than 5 pCi/gm after cleanup. The proposed standard is EPA's judgment of the most stringent cleanup condition that may reasonably be required for all the inactive mill sites. After the required cleanup, radon emission and gamma radiation from the site will be within the normal variations that occur among nearby undisturbed land areas.

Exposure even to normal concentrations of indoor radon decay products carries some health risk, but we believe Congress intended that tailings should not unreasonably increase this risk. Concentrations of indoor radon decay products in normal buildings, however, vary widely, and depend on many factors. Of the alternative forms for a remedial action standard for indoor radon decay products, we decided that limiting the total concentration is the only workable form. We believe that the proposed remedial action level of 0.015 WL (including background) for occupied or occupiable buildings is the most protective level that can be justified. Experience in a cleanup program in Grand Junction, Colorado, and studies performed by EPA for homes in Florida indicate that remedying concentrations greater than 0.015 WL usually is practical. We have concluded from studies of radon decay product concentrations in normal houses that efforts to reduce levels significantly below 0.015 WL by removing tailings would often be unfruitful and would waste the money spent.

The proposed limit is based on the hazard from breathing indoor air containing radon decay products. Gamma radiation, however, can penetrate the body from the outside. We expect that the indoor radon decay product standards generally will be met by removing tailings from under and around the building; this will eliminate any indoor gamma radiation problem. For some buildings, however, removing the tailings may be impractical, more for engineering reasons than because of cost. Cleaning the air, improving ventilation, and sealing the walls and floors are alternatives, but if these methods are used, standards will be needed to limit the occupants' exposure to gamma radiation.

If the gamma radiation standard is too lenient, methods other than removal of tailings could be used more often. Because removal is definitive and its effectiveness long lasting, however, it is the remedial method we wish most to encourage. To this end, our proposed action level for gamma radiation, 0.02 mR/hr above background, allows some limited flexibility in the methods chosen to reduce indoor radon decay product concentrations. Reducing the standard much below 0.02 mR/hr would virtually eliminate this flexibility and provide only a small additional health benefit to a few individuals.

The proposed standards will be implemented by the Department of Energy, with the concurrence of the Nuclear Regulatory Commission and in cooperation with other Federal agencies, affected States, and Indian tribes. Because the proposed standards probably will not fit exceptional circumstances, we have provided criteria for determining when exceptions to the standards are justified. In such cases, DOE, with the concurrence of NRC, may select and perform remedial actions which come as close to meeting the standards as is reasonable.

1: INTRODUCTION

In Public Law 95-604, the Uranium Mill Tailings Radiation Control Act of 1978 (42 USC 7901), the Congress found that uranium mill tailings at active and inactive mill operations may pose a potential and significant radiation health hazard to the public, and that every reasonable effort should therefore be made to stabilize, control, and dispose of such tailings in a safe and environmentally sound manner to prevent or minimize radon diffusion into the environment and other environmental hazards from tailings.

The Act specifically calls for EPA to set generally applicable standards for both radiological and nonradiological hazards posed by "residual radioactive materials" at certain inactive uranium mill tailings sites and at other sites where such materials are deposited. "Residual radioactive material" is (1) tailings waste remaining after uranium and other products are extracted from ore and judged radioactive by the Secretary of Energy, and (2) other waste connected with the extraction process, including unprocessed ore and low-grade material, judged radioactive by the Secretary of Energy.

The Act also requires EPA to set generally applicable standards for active uranium mill and disposal sites. The standard discussed in this Environmental Impact Statement does not address active sites. We will propose such a standard later. Our current proposal sets standards for cleaning up open lands and structures contaminated with residual radioactive material -- mainly tailings or similarly hazardous wastes -- control; and for controlling uranium mill tailings from inactive processing sites for a long time.

The Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604) names 22 inactive processing sites. Twenty-one are inactive uranium mill sites in the western United States, and the other is the location of a former rare-metals processing plant in Canonsburg, Pa. This Environmental Impact Statement primarily applies to the mill sites but also addresses the Canonsburg site, for its potential hazards and many of the methods to correct and control them parallel those of the other sites.[1]

In developing the proposed standards, we first evaluated the potential effects on public health and the environment of tailings at the designated sites. We then reviewed general approaches to controlling these effects and developed cost estimates for specific control methods. Our proposed control standards were based on such factors as improved health; longevity of control methods; limitations of institutional cost; feasibility, and the potential impact of the control methods themselves. Under PL 95-604, the Department of Energy, the affected States, and the Nuclear Regulatory Commission are responsible for implementing the standards.

---

[1] The Department of Energy formally designated the 22 sites in accord with Sec. 102 of PL 95-604. It also has identified and designated three other processing sites that require remedial action. These are located near Bowman and Belfield, North Dakota, and Baggs, Wyoming. These three sites have only recently been studied, and they appear to be among the least hazardous in the entire group (see "Uranium Mill Tailings Site Visit and Preliminary Health Impact Evaluation," a report prepared by Ford, Bacon and Davis Utah, Inc., October 17, 1979). Data on them is much less complete than for the other designated sites, so we have omitted them from our analysis. We believe that their omission has little effect on our conclusions.

In this Draft EIS, Chapter 2 summarizes the history of the uranium milling industry and briefly surveys the designated sites. Chapter 3 reviews their radiological and nonradiological characteristics and discusses off-site contamination of nearby land and buildings. Chapter 4 outlines the potential health hazards posed by uranium mill tailings with estimates of the risks to people living nearby, in the region, and in the continental United States. Chapter 5 examines alternative degrees of control. Chapter 6 presents monetary cost estimates for various engineering approaches and discusses such other significant control factors as duration, effectiveness, and occupational hazards. Chapter 7 addresses off-site contamination and factors weighed in cleaning up contaminated land and structures. Chapter 8 explains how we chose the proposed standards. Chapter 9 discusses the process of implementing the standards, and the anticipated effects.

2: URANIUM MILLING OPERATIONS

2.1 History of Uranium Milling Operations

A brief history of uranium milling appeared in the Nuclear Regulatory Commission's Draft Generic Environmental Impact Statement (NR 79). The history summarized two papers by Merritt (ME 71) and Facer (FA 76) and, for its relevance to this report, is repeated here.

> In the past 35 years the uranium industry has undergone a series of transformations, the element changing almost overnight from a commodity of only minor commercial interest to one vital for nuclear weapons and, now, to its important peaceful use as a fuel for generation of electrical energy. With each change there has been a surge of interest in ore exploration and development, and in new and expanded production facilities.
>
> The military demand for uranium beginning in the early 1940s had to be met from known sources of supply. The rich pitchblende ores of the Shinkolobwe deposit in the Belgian Congo and the Great Bear Lake deposit in Canada supplied uranium during the war years and were supplemented by production from treatment of old tailings dumps and a few small mines in the Colorado Plateau area. These high-grade ores and concentrates were refined by an ether extraction technique adapted from analytical procedures. Crude ore milling processes for low-grade ores used during this period reflected little change from methods used 40 years earlier (at the turn of the last century) with uranium recovery from the

leach solutions based on several stages of selective precipitation. Milling costs were high and overall recovery was low, as judged by current standards.

With passage of the Atomic Energy Act of 1946, a strong emphasis was placed on the discovery and development of new worldwide sources of uranium. At the same time, the research efforts begun earlier were expanded in scope and magnitude to advance the process technology. These efforts led to greater use of lower grade ores than previously had been considered feasible, such as the uranium-bearing gold ores in South Africa, as a source of uranium, and to the discovery and developemnt of large, low-grade deposit in the Beaverlodge, Elliot Lake, and Bancroft regions of Canada.

In the United States, prospecting and mining for uranium were encouraged by the Atomic Energy Commission (AEC) through guaranteed fixed prices for ore, bonuses, haulage allowances, establishment of ore-buying stations and access roads, and other forms of assistance. These incentives led directly to an increase in the known mineable reserves of ore in the western United States from about 9×10^5 metric tons (MT) (1×10^6 short tons (ST)) in 1946 to 8.1×10^7 MT (8.9×10^7 ST) in 1959. Programs also were initiated to examine other possible sources of uranium and to develop methods for processing these materials. AEC purchases from 1948 through 1970 totalled approximately 3 x 105 MT (3.3 x 105 ST) of U_{308}, of which nearly 1.6 x 105 MT (1.8 x 105 ST) with a value of about $3 billion were supplied from domestic sources.

During the peak production years in the United States, from 1960 through 1962, the number of operating mills (excluding plants producing by-product uranium from phosphates) varied from 24 to 26, with total annual production exceeding 1.5 x 104 MT (1.7 x 104 ST) of U_{308} from the treatment of about 7 x 106 MT (8 x 106 ST) of ore.

In 1957, it was apparent that very large ore reserves had been developed, and that additional contracts, which were the main incentive for exploration by potential producers, would lead to commitments exceeding government requirements through 1966. In 1958, the AEC withdrew its offer to purchase uranium from any ore reserves developed in the future. This led to shutdowns of mills after expiration of contracts and to stretching out of deliveries under long-term contracts in the United States, Canada, and South Africa.

Total production of U_{308} through 1977 from U.S. sources is estimated at about 2.7 x 105 MT (3 x 105 ST). The amounts of ore used in the production of this U_{308}, and the approximate amount of tailings produced, were expected to reach 1.3 x 108 MT (1.4 x 108 ST) by the end of 1977. Of this total, about

20%, or 2.3×10^7 MT (2.5×10^7 ST), is located at inactive mill sites and the balance (80%) is located at currently active mill sites.

Nuclear power's growth in the 1970's and projections of the future need for nuclear fuel spurred increased exploration for ore and construction of mills in the last part of the decade.

2.2 Status of Milling Sites

Table 2-1 shows the number of active and inactive uranium milling sites in the United States at five-year intervals. This listing omits several pilot facilities that produced uranium before 1950.

The hazards posed by mill tailings were incompletely recognized in the uranium industry's early years, and, while the Atomic Energy Act of 1954 instituted licensing of mill operators, tailings remained free of controls. Numerous studies have assessed tailings hazards, and several State and Federal agencies -- Colorado's, for example -- have acknowledged a need for controls. But no comprehensive program to control tailings began until after the Subcommittee on Raw Materials of the Joint Committee on Atomic Energy conducted Congressional hearings in 1974. Studies supported by the Energy Research and Development Administration (later merged into the Department of Energy) then followed. The first set of studies (the Phase I studies) determined the current status and general scope of the hazards at inactive mill tailings sites. The second set (the Phase II studies)

TABLE 2-1

Number of Active and Inactive Uranium Mill Sites(a)

Year	No. of Active Sites	No. of Inactive Sites	Total
Up thru 1940	4	0	4
1945	5	1	6
1950	9	1	10
1955	12	2	14
1960	30	4	34
1965	21	13	34
1970	15	20	35
1975	15	24	39
1980 (Jan)	21(b)	25	46(b)

(a) From References JO 77, AU 70, and TH 79.

(b) Not included are 8 solution mining operations, 4 phosphoric acid by-product plants, and 4 heap leaching operations.

assessed them in greater detail and discussed various alternatives for controlling them.

2.3 The Inactive Sites

The Congressional hearings noted above took place on March 12, 1974. The bills discussed, S.2566 and H.R. 11378, were identical. They proposed that the U.S. Atomic Energy Commission (later the Energy Research and Development Administration and now the Department of Energy) and the State of Utah jointly assess and act appropriately to limit people's exposure to radiation originating from the Vitro uranium mill tailings site at Salt Lake City, Utah.

EPA endorsed the bills' objectives but, with AEC, recommended instead that the two agencies, in cooperation with the states, assemble comprehensive studies of all inactive mill sites. The studies would be divided into two phases. The Phase I studies would establish the sites' condition, ownership, surroundings, and the need, if any, for more detailed studies. The Phase II studies would, as needed, evaluate the hazards and analyze alternative solutions and their costs. Congress accepted the proposal, and in May 1974 the Phase I studies began.

2.3.1 The Phase I Studies

The Phase I studies conducted during 1974 summarized conditions at 21 inactive uranium milling sites (See Table 2-2) and outlined the detailed engineering assessments to be performed in Phase II.

TABLE 2-2

Inactive Mill Sites

Site	Phase I	Phase II	Designated under PL 95-604
ARIZONA			
1. Monument Valley	x	x	x
2. Tuba City	x	x	x
COLORADO			
3. Durango	x	x	x
4. Grand Junction	x	x	x
5. Gunnison	x	x	x
6. Maybell	x	x	x
7. Naturita	x	x	x
8. New Rifle	x	x	x
9. Old Rifle	x	x	x
10. Slick Rock (NC Site)	x	x	x
11. Slick Rock (UC Site)	x	x	x
IDAHO			
12. Lowman	x	x	x
NEW MEXICO			
13. Ambrosia Lake	x	x	x
14. Shiprock	x	x	x
NORTH DAKOTA			
15. Belfield			x
16. Bowman			x
OREGON			
17. Lakeview	x	x	x
PENNSYLVANIA			
18. Canonsburg (a)		x(b)	x
SOUTH DAKOTA			
19. Edgement (c)			
TEXAS			
20. Falls City	x	x	x
21. Ray Point	x	x	

(continued)

TABLE 2-2 (continued)

Site	Phase I	Phase II	Designated under PL 95-604
UTAH			
22. Green River	x	x	x
23. Hite(e)	x	x	x
24. Mexican Hat	x	x	x
25. Monticello (f)	x	x	x
26. Salt Lake City	x	x	x
WYOMING			
27. Baggs			x
28. Converse County	x	x	x
29. Riverton	x	x	x
Totals	21	23	25

(a) Former rare-metals plant; not an inactive uranium mill site

(b) Study done as part of Formerly Utilized MED/AEC Sites Remedial Action Program

(c) Owned by TVA

(d) Uranium not sold to U.S. Government

(e) Covered by waters of Lake Powell

(f) Owned by Department of Energy

The Phase I studies excluded several sites: Monticello, Utah (owned by the Department of Energy); Edgemont, South Dakota (owned by the Tennessee Valley Authority); Hite, Utah (covered by Lake Powell, a lake created by the 1963 construction of the Glen Canyon Dam after high-grade tailings were removed from the site); Riverton, Wyoming (licensed by the AEC to a private owner at the time of the Phase I studies but later added to the Phase II studies); and Bowman and Belfield, North Dakota, Baggs, Wyoming, and Canonsburg, Pennsylvania.

As a sample of the Phase I studies, the following excerpts from the Phase I Summary discuss the Vitro site at Salt Lake City, and stabilization, off-site radiation, and the use made of inactive mill sites.

> ### The Vitro Site, Salt Lake City
>
> The existing conditions at the Vitro site in Salt Lake City are completely unsastisfactory. The tailings pile, located at the center of population of Salt Lake valley, is largely uncovered and subject to continuing wind and water erosion. While the extent of exposure of the population to radiation from this source may be difficult to quantify, the spread of radioactivity is readily detectable for considerable distances offsite. Because of the continued industrial growth in the area, the population exposure can be expected to increase. The site is only partially fenced and is readily accessible to the public. If the tailings pile were to be stabilized by covering and

vegetation at the present site, their integrity would be difficult to maintain. While contamination of surroundings from blowing dust could be reasonably well controlled, the emanation of radon gas and leaching of radium into ground waters would be expected to continue. The representative of AEC, EPA and the State of Utah concur that the present site is unsuited to long-term radioactive tailings storage, and the Phase II study of the Vitro site should be directed principally toward a plan for removal to a more suitable location.

Stabilization

The conditions found at the 21 mill sites are summarized in (Table 2-3). Tailings stabilization at six sites had not been attempted at all. However, following the site visit, the State of Oregon notified the owner that stabilization should be undertaken as soon as possible at Lakeview. The chemical surface coating used at Tuba City, Arizona, has broken up after only a few years weathering and is considered unsuccessful. The conditions at Shiprock, New Mexico, on the Navajo Reservation have been considerably aggravated as a result of the operation of a heavy earth-moving-equipment school on the site. The State of Colorado adopted regulations in 1966 for stabilization and control of uranium mill tailings by the mill owners. The substantial efforts made in that state have been fairly successful. In no case, however, was it found that the results could be considered entirely satisfactory. Some erosion and loss of cover was noted

TABLE 2-3

SUMMARY OF CONDITIONS NOTED AT TIME OF PHASE I SITE VISITS

	Condition of Tailings	Condition of Buildings & Structures on Millsite	Mill Housing	Adequate Fencing, Posting, & Surveillance	Property Bounded by River or Stream	Dwellings &/or Industry Within 1/2 Mile	Visual Evidence Wind &/or Water Erosion	Possible Ground &/or Surface Water Contamination	Tailings Removed From Site for Private Use	Other Hazards On-Site
ARIZONA										
Monument Valley	U	R	N	No	No	Yes	No	No	No	No
Tuba City	U	PR-UO	E-O	No	No	Yes	Yes	No	No	Yes
COLORADO										
Durango	P	PR-UO	N	Yes	Yes	Yes	Yes	No	Yes	Yes
Grand Junction	S	PR-O	N	Yes	Yes	Yes	No	No	Yes	No
Gunnison	S	B-O	N	Yes	No	Yes	No	Yes	No	No
Maybell	S	R	N	Yes	No	No	No	No	No	No
Naturita (a)	S	PR-O	E-P	Yes	Yes	No	Yes	Yes	No	No
New Rifle	P	M-O	N	Yes	Yes	Yes	Yes	Yes	No	No
Old Rifle	S	PR-OU	N	Yes	Yes	Yes	No	Yes	Yes	No
Slick Rock (NC)	S	R	N	No	Yes	Yes	Yes	No	No	No
Slick Rock (UC)	S	R	E-P	Yes	Yes	Yes	No	No	No	No
IDAHO										
Lowman	U	R	N	No	Yes	Yes	No	No	Yes	No
NEW MEXICO										
Ambrosia Lake	U	PR-O	N	Yes	No	No	Yes	No	No	No
Shiprock	P	PR-O	E-O	Yes	Yes	Yes	No	No	Yes	Yes
OREGON										
Lakeview	U	M-OU	N	Yes	No	Yes	Yes	No	No	No
PENNSYLVANIA										
Canonsburg(b)	U	B-O	N		Yes	Yes	Yes		Unknown	No
TEXAS										
Falls City	P	M-OU	N	Yes	No	No	No	Yes	No	No
Ray Point	P	M-OU	N	Yes	No	No	No	No	No	No
UTAH										
Green River	S	B-O	N	Yes	No	Yes	Yes	Yes	No	No
Mexican Hat	U	B-O	E-O	No	No	Yes	Yes	Yes	No	No
Salt Lake City	U	R	N	No	Yes	Yes	Yes	Yes	Yes	Yes
WYOMING										
Converse City	U	R	N	No	No	No	No	No	No	No

(Continued)

TABLE 2-3 (continued)

Column 1.
S - Stabilized, but requires improvement
P - Partially stabilized
U - Unstabilized

Column 2.
M - Mill intact
B - Building(s) intact
R - Mill and/or buildings removed
PR - Mill and/or buildings partially removed
O - Occupied or used
UO - Unoccupied or unused

Column 3.
N - None
E - Existing
O - Occupied
P - Part occupied

(a) Pile moved to new location after this study.
(b) Not in Phase I, but information included for completeness

in all cases, and the vegetation was generally not self-sustaining without continued maintenance, usually including watering and fertilization. Thus, the stabilization work done to date represents a holding action, sufficient for the present, but not a satisfactory answer for long-term storage.

Offsite Radiation

The mechanisms known to cause spread of radioactivity from the sites are:

1. Windblown solids.
2. Radon gas and its decay products.
3. Deliberate removal of tailings and other materials for offsite use.
4. Water erosion and dissolution.
5. Ground water and soil contamination.

In addition, low grade ores and mine wastes have occasionally been spilled or dumped offsite.

Evidence exists of all these mechanisms causing some degree of increase in radioactivity above natural background. In no other location was there evidence of the widespread use of tailings in building construction such as occurred in Grand Junction, Colorado. Nevertheless, there are some habitable structures in several other locations where tailings use is suspected.

Measurements of dust concentrations in air made near tailings piles in the past have not indicated significant hazard from inhalation. However, the significance of blowing dusts settling out in the general vicinity over a period of many years has not been thoroughly evaluated.

The EPA has held the position for some time that radon gas emanating from a tailings pile may cause a detectable increase in airborne radiation levels in the vicinity of a tailings pile, roughly within half a mile. The gas will diffuse readily into existing structures, but its particulate decay products would tend to remain inside, possibly causing a buildup in radioactivity within the structure. There is little data available to support this hypothesis, but it needs to be checked carefully, as it could have significant bearing on decisions regarding removal of tailings piles from populous areas. High radon decay product levels were found in structures close to the Vitro pile, but the possibility of their having been built over tailings has not been excluded.

Water erosion does not appear to have been a significant factor in the off site migration of tailings. However, the movement of radium and soluble salts into the sub-soil in areas with high water table needs further evaluation. In a few locations tailings piles are located near water courses where flooding can be a problem.

Use of Mill Sites

Where housing and other structures remain from the milling operations they have been frequently put to use. Housing at Tuba City, Naturita, Slick Rock, Shiprock and Mexican Hat is occupied. Buildings on the mill sites at Gunnison, Naturita, Shiprock, Green River and Mexican Hat are being used for warehousing, schools and other purposes. At several sites, buildings are still used for company activities. At Salt Lake City a sewage disposal plant is operating on the site. Construction of an automobile race track was begun in the middle of the tailings pile. It was subsequently stopped by the State upon recommendations of AEC and EPA. The pressure for use of sites in urban areas is likely to increase with time consistent with projected population growth. None of the areas formerly occupied by milling facilities, ore stockpiles, etc., have been examined to determine the depth of soil contamination, or suitability for future unrestricted use.

Table 2-3 summarizes the widely varying conditions at the time of the Phase I site visits (AE 74, Table I). Table 2-4 summarizes the Phase I studies and presents the recommendations made for Phase II studies of potential remedies for each site (AE 74, Table II).

Since the Phase I studies, the Naturita pile has been moved and the Shiprock site has been cleaned up and the pile stability improved. Tailings from the Monument Valley, Falls City, and Ray Point sites have been removed and used as construction material. At some sites buildings

TABLE 2-4

SUMMARY OF PHASE I FINDINGS AND PRINCIPAL ACTION TO BE STUDIED IN PHASE II

AS DETERMINED BY AEC (NOW DOE)

	Years Operated	Tons of Tailings (in thousands)	Ra in Ci	I	II	III	IV	V	VI	VII
Arizona										
Monument Valley	1955-67	1,200	50				X		X	
Tuba City	1956-66	800	670		X	X	X	X		
Colorado										
Durango	1943-63	1,555	1,200	X	X	X		X		
Grand Junction	1951-70	1,900	1,350	X	X	X		X		
Gunnison	1958-62	540	200	X	X	X			X	
Maybell	1957-64	2,600	640		X	X				
Naturita	1939-63	704	490		X	X				
New Rifle	1958-72	2,700	2,13[illegible]	X				X	X	
Old Rifle	1924-58	350	320	X	X	X		X	X	
Slick Rock (NC)	1931-43	37	30		X					
Slick Rock (UC)	1957-61	350	70		X	X				
Idaho										
Lowman	1955-60	90	10		X		X			
New Mexico										
Ambrosia Lake	1958-63	2,600	1,520		X	X	X			
Shiprock	1954-68	1,500	950	X	X	X	X			
Oregon										
Lakeview	1958-60	130	50		X	X	X			X
Texas										
Falls City	1961-73	2,500	1,020		X					X
Ray Point	1970-73	490	230		X					X

(Continued)

TABLE 2-4 (continued)

SUMMARY OF PHASE I FINDINGS AND PRINCIPAL ACTION TO BE STUDIED IN PHASE II

AS DETERMINED BY AEC (NOW DOE)

	Years Operated	Tons of Tailings	Ra in Ci	I	II	III	IV	V	VI	VII
Utah										
Green River	1958-61	123	20		X	X				
Mexican Hat	1957-65	2,200	1,560		X	X				
Salt Lake City	1951-68	1,700	1,380	X	X	X	X	X	X	
Wyoming										
Converse County	1962-65	187	60				X			X
Totals		25,256	13,950							

Notes:

I - The removal of tailings and other radioactive materials from the site to a more suitable location.

II - Stabilize tailings or complete or improve stabilization to prevent wind and water erosion.

III - Decontamination of millsite or immediate area around tailings pile.

IV - Complete or improve fencing and posting of millsites and tailings areas.

V - Determine levels of radioactivity in structures where tailings may have been used in construction and determine costs and measures needed for remedial action where warranted.

VI - Conduct ground water surveys in immediate area of millsite and tailings.

VII - No phase II study proposed at this time.

and other architectural features, such as fences, have changed; all buildings have been removed at the Shiprock site, for example. And wind and water have eroded tailings at all of the sites.

2.3.2 The Phase II studies

The Phase II studies (FB 76-78) of 23 sites (Table 2-2) began in 1975. The studies fixed site ownership and determined hydrologic, meteorologic, topographic, demographic, and socioeconomic characteristics of the inactive mill sites and alternative sites to which tailings might be moved. Radiological surveys of air, land, and water near the tailings sites included estimates of exposures to individuals and nearby populations and identification of offsite use of tailings. Finally, the studies developed alternative remedial action plans for each site and analyzed each plan's cost.

The scope of the Phase II studies at each site was guided by the recommendations of the Phase I studies (Table 2-4). This Environmental Impact Statement incorporates many of the results of these studies, but the Phase II reports themselves offer more detailed, site-specific information.

References for Chapter 2

(AE 74) U.S. Atomic Energy Commission, 1974, "Phase I Studies of Inactive Uranium Mill Sites and Tailings Piles" (Summary and individual site reports).

(AU 70) Augustine, R.J., August 1970, "Inventory of Active Uranium Mills and Tailings Piles at Former Uranium Mills," ISDHEW.

(FA 76) Facer, J.F., Jr., "Production Statistics" (of the Uranium Industry), presented at Grand Junction Office Uranium Industry Seminar, Department of Energy, October 1976.

(FB 76-78) Ford, Bacon, and Davis, Utah, Inc., "Phase II--Title 1, Engineering Assessment of Inactive Uranium Mill Tailings," 20 contract reports for Department of Energy Contract No. E(05-1)-1658, 1976-78.

(JO 77) Jones, J.Q., October 1977, "Uranium Processing Developments," Grand Junction Office, Department of Energy.

(ME 71) Merritt, R.C., 1971, "The Extraction Metalurgy of Uranium," Colorado School of Mines Research Institute, Golden, Colorado.

(NR 79) U.S. Nuclear Regulatory Commission, "Generic Environmental Impact Statement on Uranium Milling," April 1979, NUREG-0511.

(TH 79) Personal conversation with John Themelis, October 1979, Grand Junction Office, Department of Energy.

3: SOURCE TERMS

3.1 Introduction

In assessing the potential health and environmental impact of the tailings, the "source terms" - - that is, the amounts and concentrations of radioactivity and toxic chemicals in the tailings piles and in off-site contamination -- are particularly important. This section discusses these sources.

3.2 Radioactivity Source Terms

From 1948 through 1978, nearly 157 million tons of ore were processed at all uranium mills (DO 79), yielding some 328,000 tons of U_3O_8, a uranium-rich compound called "yellowcake." Chemicals added in processing become part of the tailings, so the tailings solids and the ore weigh about the same. The 22 inactive sites designated under PL 95-604 contribute about one-sixth of all tailings, or about 26 millions tons, deposited in piles covering about 1,000 acres (Table 3-1). The remaining tailings are at active sites licensed by the NRC or Agreement States, and will be subject to forthcoming EPA standards.

Most of the mills at the now-inactive sites used acid solvents to dissolve uranium out of the ore. All mills discharged a mixture of solid tailings and liquids to an impoundment area, unusually referred to as a tailings pond or tailings pile. Part of the liquid was recycled to the mill but most of it evaporated or seeped into the ground. Seepage of

TABLE 3-1

RADIOACTIVITY IN INACTIVE URANIUM MILL TAILINGS PILES

SITE	TONS OF TAILINGS (MILLIONS)	AREA OF TAILINGS (ACRES)	AVERAGE ORE GRADE[1] (% U_3O_8)	AVERAGE RADIUM-226[2] (pCi/g)	ANNUAL RADON RELEASE[3] (Ci/yr)	TOTAL RADIUM-226[4] (Ci)	MAX. MEASURED RADIUM-226[5] (pCi/g)	RADON-222: MEASURED RELEASE RATE[6] (pCi/m^2-sec)
1. Monument Valley, Arizona	1.2	30	0.04	50	200	50	1,300	14-29
2. Tuba City, Arizona	0.8	22	0.33	924	2,600	670	1,880	11-406
3. Durango, Colorado	1.6	21	0.25	700	1,900	1,200	1,800	35-312
4. Grand Junction, Colorado	1.9	59	0.28	784	5,900	1,350	1,800	25-656
5. Gunnison, Colorado	0.5	39	0.15	420	2,100	200	1,100	476
6. Maybell, Colorado	2.6	80	0.098	274	2,800	640	600	75-99
7. Naturita, Colorado	0.7	23	0.30	800	2,300	490	1,200	763-2,540
8. New Rifle, Colorado	2.7	32	0.31	868	3,600	2,130	1,900	70-1,400
9. Old Rifle, Colorado	0.4	13	0.36	1,008	1,700	320	5,400	210-1,300
10. Slick Rock (NC), Colorado	0.04	19	0.28	784	1,900	30	350	4-246
11. Slick Rock (UC), Colorado	0.35	6	0.245	686	500	70	120	6-24
12. Lowman, Idaho	0.09	5	0.19	532	300	10	244	50-150
13. Ambrosia Lake, New Mexico	2.6	105	0.23	644	8,600	1,520	900	40-300
14. Shiprock, New Mexico	1.5	72	0.25	700	6,400	950	4,000	53-157 (440-1200-2200)(7)
15. Lakeview, Oregon	0.13	30	0.15	420	1,600	50	420	187-710 (3-31)(8)

TABLE 3-1 -- Continued

RADIOACTIVITY IN INACTIVE URANIUM MILL TAILINGS PILES

SITE	TONS OF TAILINGS (MILLIONS)	AREA OF TAILINGS (ACRES)	AVERAGE ORE GRADE(1) (% U_3O_8)	AVERAGE RADIUM-226(2) (pCi/g)	ANNUAL RADON RELEASE(3) (Ci/yr)	TOTAL RADIUM-226(4) (Ci)	MAX. MEASURED RADIUM-226(5) (pCi/g)	RADON-222: MEASURED RELEASE RATE(6) (pCi/m^2-sec)
16. Canonsburg, Pennsylvania	0.4	18					4,200	185-296
17. Falls City, Texas	2.5	146	0.16	448	8,400	1,020	160	3-78
18. Ray Point, Texas	0.49	47	0.185	518	3,100	230	264	427
19. Green River, Utah	0.12	9	0.29	812	900	20	220	32-128
20. Mexican Hat, Utah	2.2	68	0.28	784	6,800	1,560	1,900	16-1,600
21. Salt Lake City, Utah	1.7	100	0.32	896	11,500	1,380	2,000	1-20(9) (130-300-650)(10)
22. Converse County, Wyoming	0.19	5	0.12	336	200	60	650	190-2,860
23. Riverton, Wyoming	0.9	72	0.20	560	5,100	544(11)	1,100	51-81

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(1) Phase II Reports (FB 76-78).

(2) Calculated from average ore grade, assuming 700 pCi/g per 0.25%.

(3) Calculated from average radium-226, assuming 1 pCi/m^2-sec of radon-222 is released (annual average) for each pCi of radium-226 per gram of tailings.

(4) Phase I summary Report (AE 74).

(5) Phase II Reports (FB 76-78). Value shown is for highest reported soil, sediment, or tailings sample. Tailings were not sampled in all cases.

(6) Phase II Reports (FB 76-78), unless indicated otherwise.

(7) Bernhardt, et al. (BE 75), reported values ranging from 590 to 1,320 pCi/m^2-sec for uncovered and 440 to 2,200 pCi/m^2-sec for stabilized tailings.

(8) Bernhardt, et al. (BE 75), reported values for stabilized tailings ranging from 3 to 31 pCi/m^2-sec.

(9) Measurements by FBDU are based on a sample of tailings in a barrel, with varying moisture contents.

(10) Bernhardt, et al. (BE 75), reported values for 11 sites ranging from 130 to 650 pCi/m^2-sec, with a median of about 300 pCi/m^2-sec. Measurements by Bernhardt indicated overlapping ranges of radon release rates for uncovered and covered (up to several feet) tailings.

(11) EPA-520/1/76-001.

contaminants occured at many sites, the extent depending on the location and design of the impoundment area. Some of the now-inactive mills discharged liquid directly into surface streams.

Uranium is the first member of a radioactive "decay series"; in other words, uranium decays to thorium, which in turn decays to radium, with the chain ultimately terminating with lead (see Fig. 4-1). Because of a condition called "secular equilibrium," the radioactivity of each member of the decay series is the same as that of the parent, uranium-238.

The amount of radioactive thorium in the tailings pond liquid at acid-process mills is much higher than at alkaline-process mills, because it dissolves readily in acid solvents but not in alkaline solvents. About 5% or less of the radium in the ore is dissolved by either method. Essentially all of the dissolved thorium, radium and radionuclides other than uranium are discharged to the tailings pond (SE 75).

The solid portion of the tailings can be divided into coarse sands and finer slimes. In the acid process, residual uranium and radium content in the slimes is about twice that in the sands, while thorium content appears to be about the same in both sands and slimes.

Since uranium is removed in milling, the uranium radioactivity levels in the tailings are substantially less than the radium radioactivity levels. Thorium-230 levels in tailings are probably close to those of radium-226, though the dominance of either may change within the pile because of variations in the mill process and any efforts to precipitate radium in the tailings pond.

The activity of such radium decay products as radon in tailings is somewhat lower than that of the parent radium, since radon is a gas which can escape from the pile. Only about 20% or less of the radon produced from the radium, however, leaves the tailings particles, so 80% or more of the decay products of radon are formed within the particles (CU 73). The depth of tailings and cover as well as porosity and moisture content largely determine how much of the radon leaving the tailings particles is ultimately released to the atmosphere.

Table 3-1 shows the estimated quantity of tailings, area of tailings, average ore grade, estimated average radium-226 concentration (based on average ore grade), annual radon release estimate, total curies(1) of radium, maximum measured radium concentrations, and limited information on measured radon-222 release rates. For "upgrader" sites where slimes have been removed, the average concentration is probably lower than that estimated from the average ore grade. Green River, Monument Valley, Slick Rock (UC), and Converse County were upgrader sites. The Naturita mill operated as an upgrader only for a short period before it was shut down.

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(1)The curie (Ci) is the basic unit of radioactivity, equal to 37 billion nuclear disintegrations per second.

As shown in Table 3-1, the maximum radium concentration found in samples ranged from about 1/5 to 25 times the average value estimated from the average ore grade.

3.3 Nonradioactive Contaminants

A number of nonradioactive toxic substances from ore or from chemicals used in processing have been found in the liquid and solid portions of uranium mill effluents (SE 75). Information on their concentrations in tailings and ground water at the inactive sites is part of the Phase II reports (FB 76-78). The contaminants present in a mill waste stream depend on the source and type of processing; Table 3-2 gives examples of the elements and compounds found in a tailings pile at one inactive alkaline-leach uranium mill. The ratio of the concentration in slimes to that in a "background" soil sample is included. Uranium and thorium are radioactive, but are also included in this table. Table 3-3 indicates additional elements and compounds which have been reported in other tailings piles.

Ground water has been contaminated at some inactive uranium mill sites. The primary source of such contamination within the first few decades after mill operation is the tailings pond water discharged while the pile is active. Kaufmann, et al. (KA 75), estimated that 30% of the water from two active tailings pond seeped into the ground. Purtyman, et al, estimated seepage loss from an inactive pile in New Mexico during its active life as 44% (PU 77). The NRC DGEIS on Uranium Milling uses a model which assumes a 38% water loss by seepage (NU 79), and estimates movement of seepage through unsaturated soil, formation of the seepage bulb in the

TABLE 3-2

Elements and Compounds Measured in an Inactive Tailings Pile(a)

Element or Compound	Concentration in Tailings Sands (parts per million)	Concentration in Tailings Slimes (parts per million)	Ratio of Concentration in Slimes to Background
Uranium	211	380	160
Molybdenum	--(b)	300	160
Selenium	31.3	133	100
Vanadium	204	2050	70
Arsenic	27	79	18
Chlorine	ND(c)	580	13
Antimony	0.69	2.2	5
Calcium	2830	2670	5
Cerium	90	163	5
Bromine	2.5	7.6	4
Sodium	1080	1970	4
Iron	1060	3550	3
Terbium	0.37	0.63	3
Cobalt	2.9	9.3	2.5
Aluminum	4280	6660	2
Barium	663	572	2
Europium	0.95	1.48	2
Gallium	5.5	17	2
Lanthanum	24	44	2
Manganese	335	388	2
Scandium	2.5	7.0	2
Zinc	15	68	2
Chromium	10	25	1
Potassium	2350	2110	1
Thorium	4.6	8.8	1
Titanium	1330	2140	1
Ytterbium	1.6	2.9	--
Cesium	2.4	2.4	1
Hafnium	3.6	4.8	1
Magnesium	4190	2180	1
Rubidium	82	63	1
Tantalum	0.42	0.62	1
Neodymium	41	95	--
Strontium	183	ND	--
Tungsten	0.49	ND	--

(a) (DR 78)

(b) -- indicates no data

(c) ND indicates not detected

TABLE 3-3

Additional Elements and Compounds Found in Uranium Mill Tailings[a]

Boron
Cadmium
Copper
Gold
Lead
Mercury
Nickel
Silver
Zirconium
Cyanide
Silicate

(a) (FB 76-78)

saturated soil zone, and movement of pollutants with the ground water. For its model mill, in an arid region, the NRC concluded that about 95% of the possible contamination was associated with the active phase of the pile and only 5% with the long-term losses from the inactive pile (NR 79). However, studies by Klute and Heermann (KL 78) indicate that even in dry climates precipitation can produce a downward flow of water through the tailings.

Tailings piles at inactive mill sites already have lost much of the water present when they were formed. The water has evaporated, gone underground, or run off on the surface. Any future contamination of water by the pile mainly would result from erosion, rain, flooding, or the flushing action of seasonal changes in the water table where it intersects a pile. The quality of streams and lakes could be degraded by seepage from a pile, or by tailings which run off or are blown into them. Table 3-4 indicates inactive and active sites where elevated concentrations of nonradioactive contaminants have been found in ground water near tailings piles.

3.4 Off-Site Contamination

In 1972, EPA and AEC, using a mobile detector in the vicinity of tailings sites, located areas with higher than normal gamma radiation. To determine the source, teams from EPA and the State health departments conducted further gamma surveys. At hundreds of locations, uranium mill tailings were found under or within 10 feet of structures (FB 76-78) and, at additional hundreds of locations, more than 10 feet from a structure.

TABLE 3-4

Elements/Compounds Reported in Elevated Concentrations in Ground Water in the Vicinity of Tailings Piles

Site	Contaminants
Ambrosia Lake, NM(a)	Barium, Lead, Vanadium
Ray Point, TX(b)	Arsenic
Green River, UT(c)	Arsenic, Chromium, Lead, Selenium
Gunnison, CO(d)	Arsenic, Barium, Chromium, Iron, Lead, Selenium, Vanadium
Falls City, TX(e)	Arsenic, Barium, Chromium, Iron, Lead, Selenium, Radium, Vanadium
Grants Mineral Belt, NM(f) (Active Mills)	Polonium, Selenium, Radium, Vanadium, Uranium, Ammonia, Chloride, Nitrate, Sulfate

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(a) (FB 76-78) (GJT-13)
(b) (FB 76-78) (GJT-20)
(c) (FB 76-78) (GJT-14)
(d) (FB 76-78) (GJT-12)
(e) (FB 76-78) (GJT-16)
(f) (KA 75)

(These figures exclude Grand Junction, where there is a separate remedial action program.) Following the 1972 surveys, tailings from Cane Valley, Arizona, and Edgemont, S. Dakota, have been used off-site, and in at least one case--Salt Lake City--the gamma surveys were not completed. Table 3-5 shows the number of locations near each designated site where the use of uranium mill tailings has been detected.

EPA began a complementary gamma radiation survey in the spring of 1974 to determine the extent of contamination by wind- and water-eroded tailings at the inactive uranium mill sites (DO 75). Gamma radiation from the ground was measured by adjusting detector readings for contributions from other sources, including direct and scattered radiation from the tailings pile. Gamma radiation from the ground at levels above the normal background indicated contamination by tailings. Contour lines corresponding to gamma radiation levels above background of 40 uR/hr,(1) 10uR/hr, and zero (i.e., background), were plotted on maps of each site to show the locations of contamination (FB 76-78). Table 3-6 provides estimates of the areas contaminated at a given gamma radiation level for the 20 inactive sites surveyed. The Oregon Department of Human Resources requested that the Lakeview site not be surveyed because the pile was stabilized during the summer of 1974. The Canonsburg, Pennsylvania, site also was not included.

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(1) The roentgen (R) is a unit measuring the electrical charge gamma rays release in air. A microroentgen (uR) is one millionth of a roentgen.

TABLE 3-5

Gamma Radiation Anomalies and Causes(a)

Location	Number of Anomalies Detected	Cause of Anomaly			
		Tailings	Radioactive Source or Ore	Natural Radioactivity	Unknown
Arizona					
Cane Valley(b)	19	15	4		
Cameron	3		1		2
Cutter	5		5		
Tuba City	17	7		3	7
State Total	44	22	10	3	9
Colorado					
Cameo	3	1			2
Canon City	187	36	24	99	28
Clifton	1083	159	34	14	876
Collbran	145	4	2		139
Craig	86	8	7	46	25
Debeque	109	2		1	106
Delta	43	1	3	29	10
Dove Creek	83	59	19	2	3
Durango	354	118	67	67	102
Fruita	1276	58	48	26	1144
Gateway	17	12	2		3
Glade Park	1	1			
Grand Junction(c)	14542	5178	7229(d)	–(d)	2135
Grand Valley	110	10	2		98
Gunnison	47	3	9	28	7
Leadville	91	18	2	65	6
Loma	199	10	4	4	181
Mack	90	6	2		82
Mesa	123	1	2		120
Mesa Lakes	3				3
Molina	43				43
Naturita	33	10	20	1	2
Nucla	13	3	6	2	2
Palisade	939	107	39	14	779
Plateau City	28	1			27
Rifle	810	168	27	1	614
Salida	64	6	2	52	4
Slick Rock	9	3	6		
Uravan	209	208			1
Whitewater	55		4	2	49
State Total	20,795	6191	7560(d)	453(d)	6591
Idaho					
Idaho City	3			2	1
Lowman	12	9		3	
Salmon	77	1	2	65	9
State Total	92	10	2	70	10

TABLE 3-5 (Continued)

Gamma Radiation Anomalies and Causes(a)

Location	Number of Anomalies Detected	Cause of Anomaly			
		Tailings	Radioactive Source or Ore	Natural Radioactivity	Unknown
New Mexico					
Bluewater	2	1	1		
Gamerco	5			5	
Grants	101	7	50	25	19
Milan	41	5	27	1	8
Shiprock	9	8	1		
State Total	158	21	79	31	27
Oregon					
Lakeview	18		2	10	6
New Pine Creek	4		1		3
State Total	22		3	10	9
South Dakota					
Edgemont	55	43	3	1	8
Edgemont and Dudley(e)	84	17	16	51	
Hot Springs	45		3	17	25
Provo	4	3	1		
State Total	188	63	23	69	33
Texas					
Campbellton	7		1	6	
Coughran	1			1	
Falls City	5	2		3	
Fashing	1		1		
Floresville	16			14	2
George West	10			10	
Karnes City	10	2		6	2
Kenedy	22	1	1	13	7
Panna Maria	3			3	
Pawnee	1		1		
Pleasanton	21		3	17	1
Poth	15			14	1
Three Rivers	5	1		2	2
Tilden	11			11	
Whitsett	1			1	
State Total	129	6	7	101	15

TABLE 3-5 (Continued)

Gamma Radiation Anomalies and Causes(a)

Location	Number of Anomalies Detected	Cause of Anomaly			
		Tailings	Radioactive Source or Ore	Natural Radioactivity	Unknown
Utah					
Blanding	38	10	21	3	4
Bluff	2		1		1
Cisco	2		2		
Crescent Junction	2		1		1
Green River	23	1	14	1	7
Magna	27	1	2	21	3
Mexican Hat	5		5		
Mexican Hat (Old Mill)	14	10	3	1	
Moab	125	15	83	6	21
Monticello	59	31	19		9
Salt Lake City(f)	225	70	15	76	64
Thompson	30	26	3		1
State Total	552	164	169	108	111
Washington					
Creston	3			3	
Ford	1			1	
Reardan	10			10	
Springdale	2			2	
State Total	16			16	
Wyoming					
Hudson	8		2	5	1
Jeffery City	28	13	10	3	2
Lander	86	4	9	53	20
Riverton	86	15	15	33	23
Shirley Basin	9	9			
State Total	217	41	36	94	46
Totals	22,213	6518	7889(d)	955(d)	6851

(a) (Ref. OR 73)

(b) From EPA report ORP/LV-75-2, August 1975. Cane Valley was not included in initial gamma survey program.

(c) A remedial action program for buildings with tailings has been in progress since 1972 under Public Law 92-314.

(d) Survey data for Grand Junction, Colo. does not distinguish the category "Radioactive source or ore" from "Natural radioactivity."

(e) Survey of additional anomalies conducted in 1978.

(f) Salt Lake City was not completely surveyed.

TABLE 3-6

Contaminated Areas Around Inactive Uranium Mill Tailings Piles(a)

Site	Tailings Pile	APPROXIMATE AREA (Excl. Pile) (Acres)		
		40 uR/hr above Background	10-40 uR/hr above Background	0-10 uR/hr above Background
1. Monument Valley,(b) Arizona	15	--	52	--
2. Tuba City, Arizona	27	128	169	202
3. Durango,(c) Colorado	10	--	--	--
4. Grand Junction,(d) Colorado	47	--	--	314
5. Gunnison, Colorado	30	12	26	68
6. Maybell, Colorado	81	322	452	745
7. Naturita,(e) Colorado	15	--	--	--
8. Rifle (New), Colorado	21	114	169	312
9. Rifle (Old), Colorado	20	17	44	243
10. Slick Rock(NC), Colorado	7	--	12	33
11. Slick Rock (UCC), Colorado	19	3	41	81
12. Lowman, Idaho	7(f)	--	11	16
13. Ambrosia Lake, New Mexico	104	210	390	617
14. Shiprock, New Mexico	118	--	126	229

TABLE 3-6 (Continued)

Contaminated Areas Around Inactive Uranium Mill Tailings Piles(a)

Site	Tailings Pile	APPROXIMATE AREA (Excl. Pile) (Acres)		
		40 uR/hr above Background	10-40 uR/hr above Background	0-10 uR/hr above Background
15. Lakeview,(g) Oregon	30	--	--	--
16. Canonsburg,(h) Pennsylvania	19	--	--	--
17. Falls City, Texas	142	139	256	411
18. Ray Point,(i) Texas	48	19	39	94
19. Green River, Utah	9	--(j)	44	153
20. Mexican Hat, Utah	77	--	127	457
21. Salt Lake City, Utah	94	114	198	510
22. Converse County, Wyoming	42(k)	--	88	187
23. Riverton, Wyoming	72	--	99	460

(a) Reference DO 75
(b) Rock outcroppings and scattered ore made measurements difficult.
(c) Ponds covered with topsoil. Contaminated area could not be determined.
(d) Due to extensive development around site, contaminated area could not be determined.
(e) Contamination from plume extends several miles down valley
(f) Mill residue stockpile areas
(g) Gamma survey not done, at request of State.
(h) Gamma survey not done.
(i) Not included under UMTRCA
(j) -- indicates data not available
(k) Includes tailings, overburden piles, and waste dumps. Tailings only constitute about 2.5 acres.

References for Chapter 3

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4: HEALTH EFFECTS

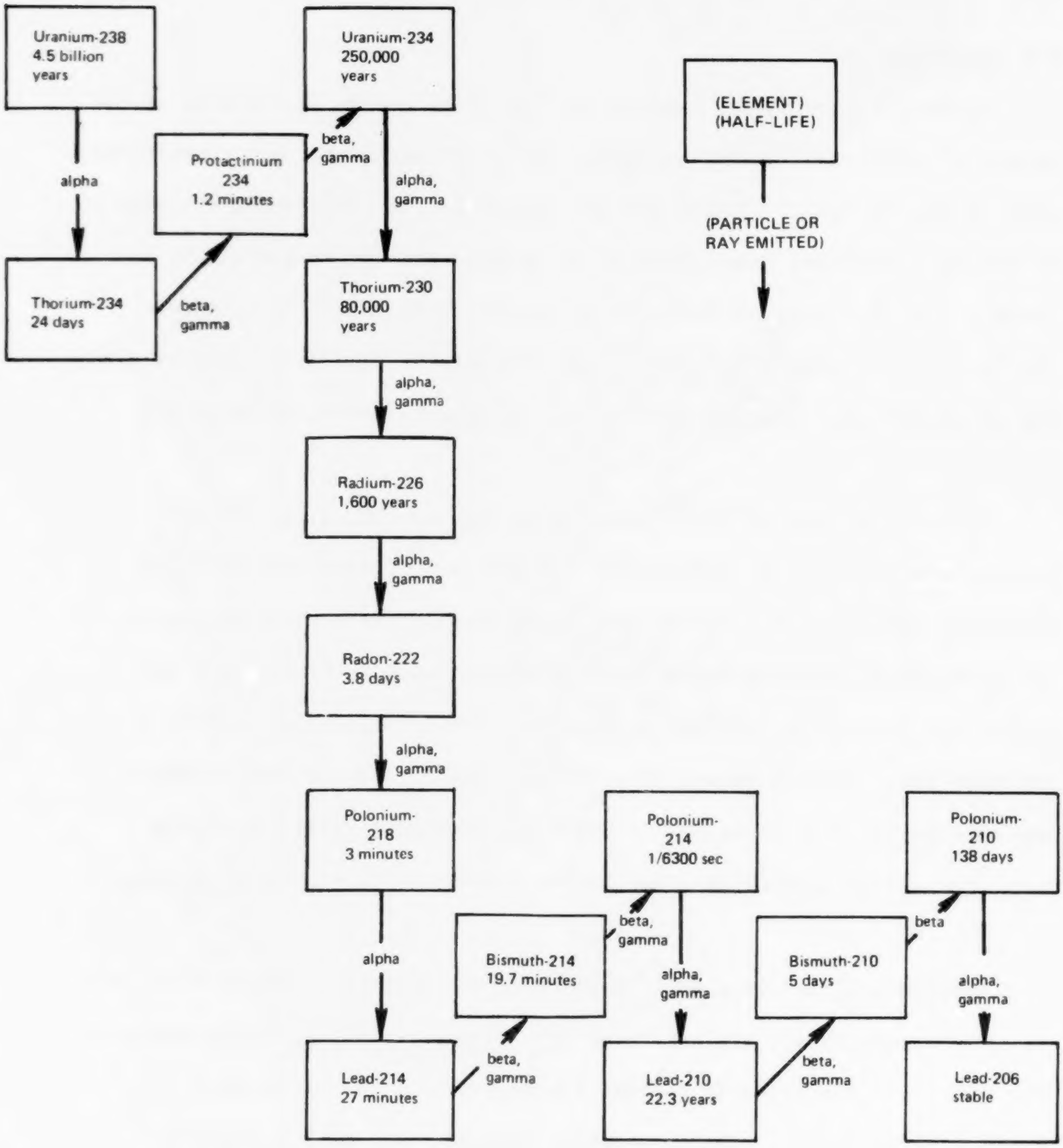
4.1 Introduction

As metallic ore waste, uranium mill tailings are unique because of the amount of radioactivity they contain. It is radioactivity that constitutes their principal health hazard, though nonradioactive toxic chemicals such as arsenic, lead, selenium, mercury, sulphates, and nitrates may also be present. Milling uranium-bearing ore removes about 90% of the uranium. The remainder, along with other radioactive material and toxic chemicals in the processed ore, is discarded in the liquid waste and solid tailings.

Most of the uranium in uranium ore is uranium-238, a radioactive isotope that decays over billions of years to become lead-206, a stable, nonradioactive element. The lengthy decay process passes through a series of intermediate elements called decay products, such as thorium-230 and radon-222; these, too, are radioactive. Fig. 4-1 traces the steps in the decay series. Uranium decays since the ore was formed millions of years ago have built up an inventory of the decay products identified in Fig. 4-1. In various concentrations, all are present in uranium mill tailings.

Uranium mill tailings emit three kinds of radiation: alpha rays, beta rays, and gamma rays. All are forms of ionizing radiation, which breaks up molecules into electrically charged fragments, or ions. In tissue, ionization can produce harmful cellular changes. At the low radiation levels naturally encountered in the environment we expect the effects of such changes to be detectable only with difficulty. Studies show, however,

FIGURE 4-1. URANIUM-238 DECAY SERIES


Uranium-238
4.5 billion years
alpha
Thorium-234
24 days
beta, gamma
Protactinium 234
1.2 minutes
beta, gamma
Uranium-234
250,000 years
alpha, gamma
Thorium-230
80,000 years
alpha, gamma
Radium-226
1,600 years
alpha, gamma
Radon-222
3.8 days
alpha, gamma
Polonium-218
3 minutes
alpha
Lead-214
27 minutes
beta, gamma
Bismuth-214
19.7 minutes
beta, gamma
Polonium-214
1/6300 sec
alpha, gamma
Lead-210
22.3 years
beta, gamma
Bismuth-210
5 days
beta
Polonium-210
138 days
alpha, gamma
Lead-206
stable
(ELEMENT)
(HALF-LIFE)
(PARTICLE OR RAY EMITTED)

that people exposed to high doses of radiation have a greater chance of developing cancer. If the ovaries or testes are exposed, moreover, the health or development of future children may be damaged.

No one can predict with precision the increased chance of cancer after exposure to radiation. EPA and other Federal agencies base risk estimates on studies of persons exposed at high doses, and assume that at lower doses the effects will be proportionately less. Sometimes this assumption may overestimate or underestimate the actual risk, but it is the best that can be done at present (EP 76).

Alpha, beta, and gamma radiation all can cause harm. But the major threat to health comes from breathing air containing radon decay products with short half-lives(1)--polonium-218, for example--and exposing the lungs and other internal organs to the alpha radiation these decay products emit. In addition, radioactive material in the tailings pile may expose people directly to gamma rays, or tailings particles may be breathed or ingested. Except within a few miles of the pile, however, the potential harm from breathing radon decay products is much greater.

The body's internal organs would still be exposed to alpha radiation even if uranium tailings piles suddenly disappeared. Radium, uranium, thorium, and other radioactive elements naturally present in ordinary rock and soil emit alpha radiation; 1 picocurie of radium per gram of soil is a typical concentration. Outdoor air contains a few tenths of a pCi of radon per liter (UN 77). Normal eating and breathing introduces these and other radioactive materials into the body, increasing the potential for cancer and genetic changes. This discussion, therefore, compares the health risks from tailings to those from normal exposure--not to justify the tailings risk, but to provide a realistic context.

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(1)A half-life is the time it takes for a given quantity of a radioactive isotope to decay to half of that quantity.

4.2 Radon and Its Immediate Decay Products

The most important decay product in the uranium-238 decay series, for the purpose of defining the longevity of tailings' radioactivity, is thorium-230, which decays to become radium-226. Because the half-life of thorium-230 is 80,000 years, uranium tailings represent an essentially permanent source of radium contamination. Radium in its usual chemical form is relatively insoluble in water, so it can be controlled much as other solid toxic materials with similar chemical characteristics. But radon-222, the radium-226 decay product, is a nonreactive radioactive gas that diffuses from the pile and becomes airborne. The half-life of radon is 3.8 days, so some radon atoms can travel thousands of miles before they decay.

As shown in Figure 4-1, the radon decay series leads through seven principal members before ending with nonradioactive lead-206. The potential health effects of breathing the short half-life radioactive decay products immediately following radon are most important. Members of the decay chain with relatively long half-lives (beginning with lead-210, with a 22-year half-life) are more likely to be ingested than breathed and represent less of a risk.

The principal short half-life products of radon-222 are polonium-218, lead-214, bismuth-214, and polonium-214--decaying, for the most part, in less than an hour. Polonium-218, the first decay product, has a half-life of just over three minutes. This is long enough for most of the electrically charged polonium atoms to attach themselves to microscopic dust particles, less than a millionth of a meter across, in the air. When breathed, such small particles have a good chance of sticking to the moist epithelium lining of the bronchial tubes in the lung. Most of the inhaled material is eventually cleared from the bronchi by mucus, but not quickly enough to keep the bronchial epithelium from being exposed to alpha rays from polonium-218 and polonium-214. These highly ionizing rays pass through several types of lung cells, but the doses they deliver to cells that eventually become cancerous cannot adequately be determined. To do so would require more detailed knowledge than we have of the deposition pattern of the radioactive particles in the lung and the distances from them to the cells. Further, there is even some disagreement about which of the several types of bronchial cells the cancers originate in. Therefore, we base estimates of lung cancer risk from inhaled radon decay products on people's exposure to radon decay products rather than on the dose absorbed in lung tissues.

Exposure to radon decay products is measured by a specialized unit called the working level (WL). A WL is any combination of short half-life radon decay products which emits 130,000 million electron volts of alpha-ray energy in one liter of air.

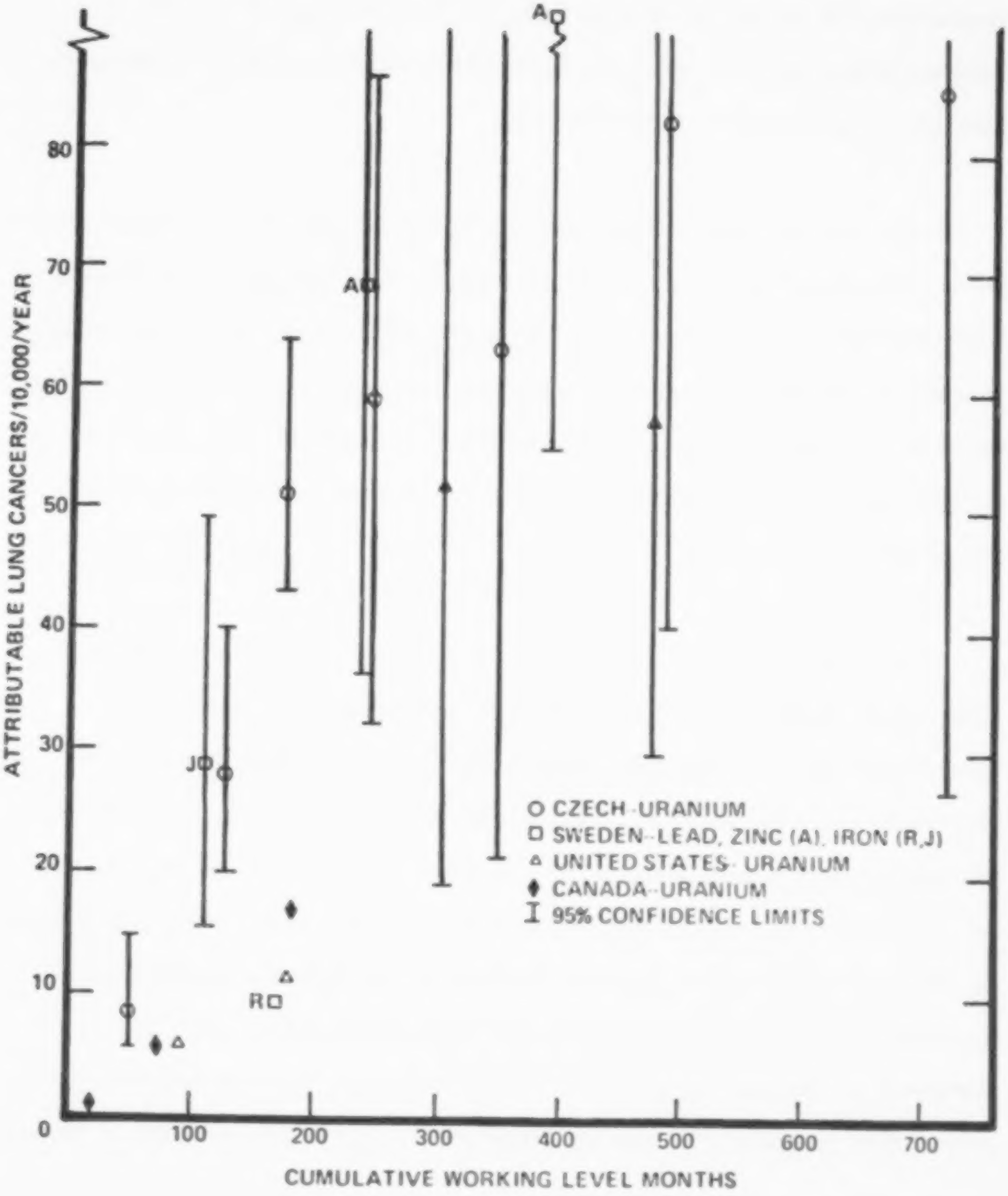
The WL was developed to measure radiation exposure to workers in uranium mines. The common unit of cumulative exposure is the working level month (WLM), or occupational exposure to air containing one WL of radon decay products for a working month, defined as 170 hours. Continuous exposure of a member of the general population to one WL for one year can be shown to be about 27 WLM (EP 78).

4.3 Estimates of the Lung Cancer Risk from Inhaling Radon Decay Products

The very high incidence of lung cancer mortality among underground miners is well documented (EP 78, AR 79). Uranium miners are particularly affected, but lead, iron, and zinc miners exposed to relatively low levels of radon decay products also show an increased lung cancer mortality that correlates with exposure. The type of lung cancer most frequently observed moreover, is rather uncommon in the general population.

Risk estimates for the general public based on these studies of miners are far from precise. First and most important, the small number of miners injects considerable statistical uncertainty (see Figure 4-2) into the number of "excess" lung cancer cases (that is, the number of cases beyond those that would occur in any event). Second, the miners were exposed to much higher levels of radon decay products than occur in the general environment. Third, the exposure levels are uncertain. Fourth, significant demographic differences between the miners and the public--the miners were healthy males over 14 years old, many of whom smoked--imperil an extension of the results of the studies to the general public.

FIGURE 4-2



Excess lung cancer in various miner groups as a function of their cumulative exposure. Note the degree of statistical uncertainty in the number of lung cancer attributable to radon daughters. After Archer (AR 79).

Information from the studies of miners can yield estimates, if not predictions, of the risks from radon decay products to the general population.(1) Since the miners being studied have not all died, however, their eventual excess lung cancers must be projected from current data by using mathematical models.

There are two ways to use the observed frequency of lung cancer deaths among the exposed miners in order to estimate the lifetime risk from inhaling radon decay products: (1) relative risk, based on the percentage increase in excess lung cancer deaths for each WLM, and (2) absolute risk, based on the number of excess lung cancer deaths per WLM and the time, in person-years, that the exposed population has been at risk at the time of the study.

For relative risk, we conclude that a 3% increase in the number of lung cancer deaths per WLM is consistent with data from the studies of the underground miners. However, because there are important demographic differences between adult male miners and the general population (EP 78), the risk to the general population may be as low as 1% or as high as 5%. For absolute risk, we use the estimate of 10 lung cancer deaths per WLM for one million person-years at risk reported by the National Academy of Sciences (NA 76). Both of these "risk coefficients" are used in this statement to examine the potential consequences of lifetime exposure to radon decay products. Unless we state otherwise, we are estimating "excess" cancer fatalities, i.e., those caused by elevated radiation levels and in addition to those from other causes.

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(1)See "Indoor Radiation Exposure due to Radium-226 in Florida Phosphate Lands" (EP 78) for such an analysis.

To estimate the number of lung cancer deaths from increased levels of radon in the environment, we have used a "life table" analysis of the additional risk due to radiation exposure (CO 78). This analysis takes account of the length of time a person is exposed and the number of years a person lives, based on the 1970 U.S. population death rate statistics, to calculate the number of premature lung cancer deaths that would occur after lifetime radiation exposure of 100,000 persons. As a basis for reference, a life table analysis for the same population indicates a 2.9% chance of lung cancer death from causes other than excess radiation. Using the relative risk model, we estimate that a person exposed to 0.01 WL over a lifetime incurs a 1.2% (1 in 80) additional chance of contracting a fatal lung cancer. This estimate was made assuming children are no more sensitive than adults. If childhood exposure results in three times greater risk than that to adults, the estimated relative risk would increase by about 50% (EP 78). Using a similar life table analysis and an absolute risk model, we estimte that a person exposed to 0.01 WL over a lifetime incurs a 0.6% (1 in 160) additional chance of contracting a fatal lung cancer. Again, equal child and adult sensitivities are assumed (EP 78).

A person's average annual risk from a lifetime of exposure may be obtained by dividing the lifetime risk estimates given above by an average lifespan of 71 years. Regardless of the risk model used or assumptions concerning child sensitivity, our firmest estimate is that increased levels of radon will produce an additional 1 to 3 lung cancer deaths per year of exposure for each 100 person-working-levels of lifetime exposure. Person-working-levels is the population's collective exposure; that is, the number of people times the average concentration of radon decay products (in working levels) to which they are exposed.

For the U.S. population as a whole, the number of cancers is larger using a relative than an absolute risk estimate, but not for all regions. The relative risk estimate for each inactive site is based on the lung cancer death rate in that area. Lung cancer death rates are lower than the national average in several of the States where inactive tailings sites are located, so at some of the localities considered in Section 4.4 the absolute risk is greater than the relative risk.

Radiation risk can be stated in terms of years of life lost due to cancer deaths as well as in estimated numbers of cancer deaths. In the relative risk model, the age at which lung cancer occurs is the same as in the general population. Since lung cancer occurs most frequently in people over 70 years of age, the years of life lost per fatal lung cancer--14.5 years on average--is less than for many other fatal cancers. The absolute risk model assumes that lung cancer fatalities occur throughout life, so that each fatality reduces the lifespan by an average of 24.6 years. Therefore, even though the estimated number of lung cancer fatalities using the relative risk model is nearly twice that using the absolute risk model, the total years of life lost in exposed populations is nearly the same.

Because we used recent population data, our assessments illustrate the current effects of tailings piles but do not predict future effects. If the population sizes and locations, lifestyle, medical knowledge, and other patterns of living affecting mortality remain unchanged, then these rates of lung cancer death could persist for the indefinite future. We will not attempt to assess future effects of tailings, which may either increase or decrease. It is sufficiently prudent, we believe, to develop standards which assume that estimated risk based on current data could persist over the indefinite future.

For convenience, we will express results as deaths per 100 years. This is simply the estimated annual rate based on current data multiplied by 100.

4.4 Effects on Local and Regional Population from Radon Decay Products

The concentration of radon decay products changes rapidly with distance from a pile, requiring complex models for determining the exposure to the local population. An accurate estimate of the collective exposure from a particular pile would include, besides the number of people exposed, the site of each residence and work place and its ventilation characteristics; the length of time a person is at each; and the wind speed and direction. All of these factors determine the level of radon decay products inhaled by an individual. Because these data are unavailable for the inactive sites, we relied upon more approximate methods to estimate regional exposure at six of the 22 inactive sites (SW 80). We selected these six because enough data to allow a quantitative analysis was available. Though limited, the sample does include all but two of the urban sites. Our purpose in performing the analysis was to illustrate the potential effects of tailings in a variety of realistic regional circumstances.

We used U.S. census tract data to establish the number and locations of exposed persons, based only on residence. (Census tract information is rather precise, in urban areas, but less so in rural areas where the tracts are large.) We assumed further that the wind pattern was symmetrical around the pile, with a constant speed of 6.5 mph. The wind speed determines the amount of dilution and, to a lesser extent, the degree of equilibrium between the emitted radon and its decay products(1). The degree of equilibrium is important because the WL for a given concentration of radon gradually increases as decay products accumulate. In this analysis we assumed a radon-radon decay product equilibrium of 70% inside all structures and in outside air more than 25 miles (40 kilometers) from the pile. We assumed 50% equilibrium in outside air within 25 miles. We defined the local population as all persons living within about six miles (10 kilometers) of the inactive pile, and the regional population as persons living more than six but less than 50 miles (80 kilometers) from the pile. We ignored population changes since 1970. A future increase in population density at several of the urban sites seems likely, but because the actual place of residence would be critical in determining exposure and resulting health impact, we didn't try to incorporate projected population growth.

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(1)An atmosphere in which radon has been introduced has zero working level initially, because radon decay products are not yet present. Eventually, radon products will build up to an "equilibrium" value that does not increase further, and the working level will be maximum. For various reasons (ventilation, "plate-out"), radon and its decay products in most atmospheres are in an intermediate relationship.

Table 4-1 summarizes the results of our study of six piles at inactive sites in terms of excess lung cancer deaths, average years of life lost per cancer fatality, and the average number of days of life lost per exposed person. The estimated number of lung cancer deaths associated with a tailings pile is highly variable, depending not only on the size of the pile but also the population density in its immediate vicinity. In contrast to the estimates of national impact, described in Section 4.5, the estimated number of fatal cancers for Utah residents based on the absolute risk model is greater than that based on the relative risk model. This is because the annual lung cancer death rates in Utah are comparatively low. The risks listed in Table 4-1 are based on just radon emissions from the tailings pile, and include no additional risk from any use of tailings material in construction.

At Canonsburg, Pennsylvania, most of the radon exposure is received by persons working at the site. We estimate the risk to these workers and to the local populations at Canonsburg as 29 or 17 fatal lung cancers per 100 years, using relative and absolute risk estimates respectively. From the limited data currently available on the Canonsburg site, the risks there

TABLE 4-1

Estimated Effect on Local and Regional Populations From Exposure to Radon Decay Products from Tailings Piles

Salt Lake City, Utah

(Local Population -- 361,000 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	72	79
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.8	1.4

(Regional Population -- 494,000 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	4	5
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.03	0.06

Mexican Hat, Utah

(No Permanent Local Population -- (1970 Census))

(Regional Population -- 14,100 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	0.05	0.05
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.01	0.02

TABLE 4-1 (cont.)

Estimated Effect on Local and Regional Populations From Exposure to Radon Decay Products from Tailings Piles

Grand Junction, Colorado (Local Population -- 39,800 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	29	18
Years of life lost per fatality	15	25
Average days of life lost per exposed person	2.6	2.9

(Regional Population -- 30,600 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	0.2	0.2
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.03	0.03

Gunnison, Colorado (Local Population -- 5,060 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	3	2
Years of life lost per fatality	15	25
Average days of life lost per exposed person	2.3	2.5

(Regional Population -- 17,060 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	0.02	0.01
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.003	0.004

TABLE 4-1 (cont.)

Estimated Effect on Local and Regional Populations From Exposure to Radon Decay Products from Tailings Piles

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Rifle, Colorado (newer pile)

(Local Population -- 2,700 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	1	1
Years of life lost per fatality	15	25
Average days of life lost per exposed person	1.5	1.7

(Regional Population -- 35,900 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	0.03	0.02
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.003	0.003

Shiprock, New Mexico

(Local Population* -- 7,200 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	4	3
Years of life lost per fatality	15	25
Average days of life lost per exposed person	1	2

*within 10 miles

(Regional Population -- 63,600 persons)

	Relative Risk Estimates	Absolute Risk Estimates
Number of fatal cancers/100 yr	.1	.1
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.007	0.01

seem comparable to those listed in Table 4-1 for the inactive piles located in urban areas.

Table 4-1 shows the estimated collective risk to people in the region. Within this group, the exposure and resultant risk to individuals depends on their distance from the pile. Table 4-2 lists the calculated exposure and estimated individual risks from lifetime exposure, as a function of distance from a hypothetical inactive pile with a radon emission rate of 10,000 curies per year. The assumed wind speed and exposure conditions are described above. Since the site is hypothetical rather than actual, Table 4-2 lists only absolute-risk estimates. At actual sites, the estimated absolute risks as a function of distance will be proportional to the annual radon emission (listed in Table 3-1). For example, at a site with emissions of 5,000 curies per year, the estimated risk to an individual who lives a given distance away will be half of that listed in Table 4-2.

Table 4-2 highlights the significance of distance. At one to three miles from the hypothetical pile, the increased radon concentration in outside air roughly equals the normal concentration in residential structures. Because distance is so important, it is useful to consider specific sites.

In several urban areas, a few individuals live and work very near the edge of tailings piles, where the concentration of radon is high. Table 4-3 lists estimated working levels in outside air at homes close to five of the urban sites. Except for the inactive pile in Salt Lake City,

TABLE 4-2

Individual Risk From Lifetime Exposure to Radon Decay Products from Tailings Piles

Radon Release Rate -- 10,000 Ci per year

Distance from Pile Edge (miles)	Exposure (WL)	Chance of Fatal Lung Cancer[(a)]
0.2	0.013	9200 in 1 million
0.4	0.005	3500 " " "
1.0	0.001	710 " " "
2.0	0.0004	280 " " "
4.0	0.0001	100 " " "
10.0	0.00002	16 " " "
20.0	0.000004	3 " " "
40.0	0.000002	1 " " "

(a)Absolute risk model.

TABLE 4-3

Estimated Risk to Nearest Residents from Inhaling Radon Decay Products from Tailings Piles[a]

(Lifetime Exposure at Current Levels)

Site	Relative Risk Estimates	Absolute Risk Estimates
Salt Lake City, UT -- (0.05 mile, 0.045 WL)(b)		
Lifetime chance of fatal cancer	0.03	0.03
Years of life lost per fatality	15	25
Grand Junction, CO -- (0.1 mile, 0.045 WL)(b)		
Lifetime chance of fatal cancer	0.04	0.03
Years of life lost per fatality	15	25
Durango, CO -- (0.1 mile, 0.026 WL)(b)		
Lifetime chance of fatal cancer	0.03	0.02
Years of life lost per fatality	15	25
Rifle, CO -- (0.5 mile, 0.007 WL)(b)		
Lifetime chance of fatal cancer	0.008	0.005
Years of life lost per fatality	15	25
Gunnison, CO -- (0.5 mile, 0.008 WL)(b)		
Lifetime chance of fatal cancer	0.009	0.006
Years of life lost per fatality	15	25

(a) A risk of 0.03 is the same as 30,000 chances in 1 million, or 30 in 1 thousand.

(b) The distance and radon concentration including background for the nearest resident to the pile (FB 76-78).

radon emissions from inactive piles are below the emission rate of 10,000 curies per year used to compile Table 4-2. The radon levels listed in Table 4-3 are based on the site-specific Ford, Bacon and Davis Engineering Assessments of inactive piles prepared for the Department of Energy (FB 76-78), and are not directly comparable to the hypothetical cases in Table 4-2. Estimates of individual risks for lifetime exposure at sites in Table 4-3 are as high as a one-in-25 chance of death from lung cancer. This is considerably greater than the risk from average residential radon, about 1 in 300 (see below).

Table 4-4 estimates the risks from the naturally occurring radon decay products found in ordinary homes near neither mill tailings nor any other specifically identified radon source. National data on radon decay products in homes is very scanty, and varies widely among individual houses. The estimates in Table 4-4 assume that the average concentration is 0.004 WL in homes occupied 75% of the time. The assumed average level of radon decay products is based on recent data on 21 houses in New York and New Jersey (GE 79), and is consistent with data obtained in other countries (UN 77). For comparison, the risks estimated in Table 4-4 are about 10% of the expected lifetime risk of lung cancer death from all causes (0.029) in a stationary population having 1970 U.S. lung cancer mortality rates.

4.5 Risks to the Continental U.S. Population from Radon Emitted from Inactive Piles

Radon emissions from tailings piles may affect health beyond the 50 miles considered above. We estimated exposure to the U.S. population

TABLE 4-4

Risk from Background Radon in Residential Structures[a]

	Estimated Risk[b]	
	Relative	Absolute
Lifetime chance of fatal lung cancer	0.004	0.002
Years of life lost per fatality	15	25
Average days of life lost per exposed person	23	18

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[a] A risk of 0.004 is the same as 4000 chances in 1 million, or 4 in 1 thousand.

[b] Calculated on the basis of 0.004 WL, home occupied 75% of the time, and 1970 U.S. mortality rates (EP 78).

beyond 50 miles using two different models for atmospheric transport. The simplest, which treats radon diffusion on the basis of very general wind patterns, yields an annual collective exposure of 0.65 person-working-level for each 1000 curies of radon emitted per year to persons living more than 50 miles (80 kilometers) from an inactive pile (SW 80). A more detailed meteorological model, developed for EPA by the National Oceanic and Atmospheric Administration (NOAA), has been used by the Nuclear Regulatory Commission (NR 79) to calculate the concentration in air of radon emitted from four sites in the western U.S. A relationship between outdoor radon concentration and working level is needed to compare the results of the two methods. Assuming that a radon concentration of 100 pCi per liter corresponds to about 0.7 WL (EP 78), the national collective exposure from the four sites considered in the NRC study ranges from 0.42 to 0.76 person-working-level per 1000 curies released per year, with an average of 0.56. This agrees reasonably well with the results of the less detailed calculations, and is adopted here. This collective exposure does not include people living within 50 miles of a pile.

Both the EPA and NOAA/NRC assessments assume a continental U.S. population of 200 million persons, based on 1970 U.S. census data. A geographically similar population distribution and a projected 1980 continental population of 220 million would increase the collective exposure by about 10%.

Estimates of lung cancer deaths among persons living more than 50 miles from inactive tailings piles are listed in Table 4-5 for 21 of the 22 inactive tailings piles. The radon emissions on which the risk estimates in Table 4-5 are based are calculated from the size of the pile and the amount of radium per gram of material, assuming a radon-222 emission rate of 1 pCi/sec for each square meter of area and for each pCi of radium-226 per gram of tailings (SW 80). Complete field measurements are unavailable and actual emissions could be considerably different from calculated values.

The total effect for persons living more than 50 miles from the 21 piles in Table 4-5 is summarized in Table 4-6, which provides different measures of health risk. They represent the total risk over 100 years for an exposed population of 200 million; on average, an individual's annual risk from the model pile is 20 billion times smaller.

4.6 Regional and National Effect from Long Half-Life Radioactive Materials

Windblown particles and the long half-life decay products of radon (beginning with lead-210) are also potential hazards (see Figure 4-1). The consequences of eating and breathing long half-life decay products cannot be established without site-specific information--food sources, for example. The only detailed study is one provided for a model active site in the NRC Draft GEIS on Uranium Milling (NR 79). As explained below, however, the NRC results apply in their entirety to few of the inactive sites. We use the results of the NRC analysis here only to identify important exposure routes and to compare their importance to that of the short half-life decay products of radon. The results shouldn't be taken as truly quantitative estimates of the risk at specific inactive sites.

The NRC model uranium mill and tailings pile is located in a sparsely populated agricultural area based on cattle ranching. The population in

TABLE 4-5

Approximate Contribution of Tailing Piles at Inactive Sites to the National Health Risk from Radon Decay Products[a]

Inactive Site	Annual Risk of Fatal Cancer[b] (deaths per year) Relative Risk	Absolute Risk
Monument Valley, Arizona	.006	0.003
Tuba City, Arizona	.04	0.02
Durango, Colorado	.02	0.01
Grand Junction, Colorado	.07	0.03
Gunnison, Colorado	.02	0.01
Maybell, Colorado	.04	0.02
Naturita, Colorado	.03	0.02
Rifle, Colorado(c)	.06	0.03
Slick Rock, Colorado(c)	.03	.01
Lowman, Idaho	.005	.002
Ambrosia Lake, New Mexico	.1	0.05
Shiprock, New Mexico	.04	0.02
Lakeview, Oregon	.02	.01
Falls City, Texas	.1	.05
Green River, Utah	.01	0.005
Mexican Hat, Utah	.065	0.03
Salt Lake City, Utah	.15	0.07
Converse, Wyoming	.003	0.001
Riverton, Wyoming	.07	0.03

(a)Does not include effects within 50 miles of the site.

(b)Years of life lost and other measures of risk are discussed in summary Table 4-6.

(c)Two inactive piles.

TABLE 4-6

Summary Table--Tailings piles at Inactive Sites(a)

Estimated National Risk of Fatal Lung Cancer from Radon Emissions(b)

Inactive Sites	Estimated Risk Relative	 Absolute
Fatal cancers per 100 years	90	40
Increased chance of lung cancer death	0.3/1,000,000	0.1/1,000,000
Years of life lost per fatality	15	25
Average days of life lost per exposed person	0.0017	0.0013

(a) Canonsburg, PA, site not included.

(b) Does not include people living within 50 miles of the site.

this region produces all of its own food. Because this scenario maximizes the dose due to food, it is inappropriate for many of the inactive sites. For tailings near urban areas, with a large number of people living close to the tailings pile, complete dependence on locally supplied food is considerably less likely.

The five sources of exposure in the NRC analysis are shown in Table 4-7. The risk from breathing short half-life radon decay products is more than 10 times greater than the next highest risk, that due to windblown tailings eaten in vegetables and meat.(1) Lead-210 and polonium-210, formed in air following radon decay, are also a source of exposure when deposited on food or breathed. According to the NRC analysis, the risk from each of these pathways equals about one-hundredth of the risk from breathing short half-life radon decay products. Even combined, the total risk from the long half-life radionuclides is much less than the risk from breathing the short half-life radon decay products. Persons living more than 50 miles from an inactive pile would be less heavily exposed and their risk would be considerably below that indicated in Table 4-7.

4.7 Impact from Gamma-Ray Exposure

Many of the radioactive materials in tailings piles are a source of gamma rays. Unlike alpha rays, which must originate within the body to

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(1)The NRC analysis for the ingestion pathway is quite conservative because the retention on vegetation assumed for deposited materials (50%), and the transfer of radium from fodder to meat (.003) are larger by a factor of five or more than is usually assumed (EP 78a, MC 79).

TABLE 4-7

Regional Impact from Uranium Mill Tailings

(NRC-GEIS Model Pile and Population)
Population at Risk--57,300 persons

	Number of Cancer Deaths Per Year
Inhaled radon decay products	.06[a]
Ingestion of windblown tailings	.004[b][c]
Inhaled lead-210/polonium-210	.0006[b]
Ingested lead-210/polonium-210	.0006[b]
Inhaled resuspended tailings	.00006[b].

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[a] EPA relative risk estimate based on 2.4 person WL/yr.

[b] From the computed data for individual radionuclides used to produce the summary tables in the NRC-GEIS (NR 79).

[c] Particles containing U-238, U-234, Th-234, Th-230, Ra-226, Pb-210, Bi-210; c.f. Fig. 4.1

become hazardous, gamma rays can penetrate both air and tissue for considerable distances. Near the edge of a pile, the exposure from gamma rays can be many times larger than the background level of gamma rays in uncontaminated areas. The concentration of gamma radiation from the pile, however, decreases rapidly with distance; at more than a few tenths of a mile from most of the inactive tailings piles, it is undetectable above normal background.

Gamma ray exposures to individuals depend on how close to the edge of a pile people live or work. The collective gamma ray dose depends on both the number of people exposed and their average dose. In a few cases individual doses can be approximated from available data, but generally this cannot be done without a variety of information, such as where people live and work and the amount of shielding provided by buildings. Outdoor gamma ray exposures in the vicinity of some tailings piles at inactive sites are summarized in Table 4-8. In several cases, even the nearest residents are far enough from the pile that they receive essentially no excess gamma radiation. At others, a few residents are located close enough to perhaps double the dose from gamma radiation that would occur without the pile. In a few cases, the dose to the nearest resident may be several times normal background levels.

In most of these localities, "normal" background due to penetrating radiation is about 100 mR per year (FB 76-78).(1) This radiation exposes

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(1)A milliroentgen (mR), or one one-thousandth of a Roentgen, is a unit of radiation exposure.

TABLE 4-8

Increased Gamma Ray Dose Rates

From Tailings Piles at Inactive Sites[a]

Site	Location of Nearest Resident Distance from Pile Edge (miles)	Annual Gamma Ray Exposure[b] (mR/yr)
Durango, CO	0.1	200-300
Grand Junction, CO	0.1	580
Gunnison, CO	0.5	--[c]
Rifle, CO	0.25	--[c]
Lowman, ID	1.0	--[c]
Ambrosia Lake, NM	1.5	--[c]
Canonsburg, PA	0.04	150
Green River, UT	0.15	--[c]
Salt Lake City, UT	0.05	465
Spook, WY	1.5	--[c]

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[a] Ambient gamma ray background at each site has been subtracted.

[b] Measured in air (Roentgens). At these energies continual exposure to 1 mR/yr gives an annual dose of 1 mrem.

[c] No detectable increase above background.

the total body, so that all organs are at risk. The estimated frequency of fatal cancer and serious genetic effects due to a lifetime exposure of 100 mR per year is listed in Tables 4-9 and 4-10. People who live or work near tailings piles will incur higher risks from long-term exposures than those listed in the tables in proportion to the excess of their annual dose rate above 100 mR per year.

In summary, information does not allow calculation of the collective gamma ray dose and risk to all persons living or working near the inactive piles, but the total impact is small because the gamma-ray intensity falls rapidly with distance from the pile.

4.8 Hazard from Water Contamination

4.8.1 Introduction

Evaluating the potential effects of nonradioactive toxic substances in tailings requires different methods than those used for radioactive substances. The basis for radiation risk estimates is that all ionizing radiation can produce cancer, and that the probability increases with the dose.(1) With nonradioactive toxic materials, however, where the effect varies with the material, and the severity of the effect--but not its probability of occurring--increases with the dose, a classical analysis of toxicity is used. Moreover, because the body can detoxify some materials

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(1)Many nonradioactive substances can induce cancer in experimental animals (GO 77, VE 78). However, for nonradioactive substances found in uranium mill tailings, we do not feel that dose-response relationships adequate for estimating risks for oral intake have been developed.

TABLE 4-9

Estimated Lifetime Risk of Fatal Cancer from Total Body Gamma-ray Exposure at 100 mR/y

	Estimated Risk(a)	
	Relative	Absolute
Lifetime chance of fatal cancer	5 in 1000	.8 in 1000
Years of life lost per fatality(b)	14	23
Average days of life lost per exposed person	24	7

(a) Lifetime risk plateau.

(b) Based on a normal life span of 70.7 years.

TABLE 4-10

Estimated Risk of Serious Genetic Abnormalities

From Gonadal Dose of 100 mR per year

	First Generation	All Succeeding Generations
Risk per 1000 live births	0.04 to 0.6	0.14 to 5
Currently observed in U.S.A. (per 1000 live births)	60 to 100	

or repair the effects of small doses, often no toxic effects occur below threshold doses. With radiation, on the other hand, we assume there is no dose below which effects do not occur.

Because of these differences, we cannot construct a numerical risk assessment for nonradioactive toxic substances. We can, however, qualitatively describe the risks of toxic substances in terms of their likelihood of reaching people (or animals, or agricultural products); concentrations at which they may be harmful; and their toxic effects.

4.8.2 Movement of Toxic Chemicals from Tailings

Tailings can contaminate both surface and ground water. Wind erosion, floods, tailings slides into adjacent streams, seepage through the pile, or runoff of rainwater all may cause surface water contamination. Ground water contamination can occur only through seepage into an underlying aquifer (a water-bearing layer of permeable rock). Since people may draw water from a single underground source at many different places, exposure to toxic chemicals greatly depends on the way the contaminants move. Since their movement through lakes and streams is familiar, the following discusses movement of dissolved contaminants in the ground.

Not enough information is available to estimate the chance that toxic substances from tailings will move through water and expose people to them. Migration of these substances in ground water near tailings piles, however, has been observed. Chemical and hydrological principles can identify substances generally most likely to enter and be carried through ground water, though the specific substances will vary among the sites.

Some organic compounds--amines, kerosene and higher alcohols, for example--are present in tailings from acid leach mills. But the main long-term ground water hazard is from leached inorganic toxic substances and radioisotopes. Movement of contaminants to ground water depends on complex chemical and physical properties of the underground environment, and on such climate conditions as precipitation and evaporation. Chemical and physical processes in the subsoil remove a portion of some contaminants from water passing through it. Contaminants including selenium, arsenic, and molybdenun, however, can occur in forms which are not removed.

Studies of leaching at tailings piles (DR 78) and leachates from municipal land fills (EP 78b) help determine which substances generally will be relatively mobile or immobile, and which will have a mobility which varies with local conditions (EP 78c). Limited studies of pollutant migration into ground water near tailings piles tend to confirm estimates using other methods of elements that will be most mobile (FB 76-78, KA 76, DA 77). There has been no systematic study, however, to establish the magnitude of ground water contamination for tailings at either active or inactive sites.

Based on available information, chromium, mercury, nickel, arsenic, beryllium, cadmium, selenium, vanadium, zinc, and uranium have a high probability of being mobile. Lead, radium, and polonium are not predicted to be mobile near tailings piles, but they appear to be mobile at some locations. Data to suggest or confirm mobilities near tailings piles for the other toxic elements are not available, but conservative assumptions should be used for ions which are generally mobile, such as nitrate, chloride, and sulfate. Certain anions (of arsenic, manganese, molybdenum, and selenium, for example) and organic complexes of trace metals may also be relatively mobile, although confirming field data from tailing pile studies are extremely limited. If, however, seepage of substances known to have high mobility is appreciably prevented or reduced, then it would seem logical that those for which no data are available should also be controlled.

When contaminated water from tailings reaches ground water, some mixing generally will occur. Except in very coarse or cracked media, through which contaminants flow relatively unimpeded, concentrations of contaminants reaching ground water will likely be reduced along the flow path by dispersion, and by absorption, adsorption, and ion exchange with the ground material. The level of users' exposure to contaminated ground water depends on the amount consumed as well as the level of contamination. Consumption depends on the palatability and quality of the water, the purposes for which it is used, and the number of users. Available data indicate that tailings have contaminated some private wells in the Grant's Mineral Belt in New Mexico (KA 76) with toxic substances whose concentrations greatly exceed the National Interim Primary Drinking Water Regulations that apply to public drinking water supplies (EP 76a).

4.8.3 Toxicity of Major Toxic Substances Found in Tailings

There is little data to estimate the probability or the level of exposure to contaminated water, but reasonably good information exists on its potential toxic effects. No acute effects--death in minutes or hours--could occur except by drinking liquid direct from a tailings pond. Severe sickness, or death within days to weeks, from the use of contaminated ground water is possible, but unlikely.

Chronic toxicity, from the continuous consumption of contaminants at rather low concentrations, could be a problem. Toxic substances can accumulate slowly in tissues, causing symptoms only after some minimum amount has accumulated. Symptoms of chronic toxicity develop slowly, over months or years.

Tables 3-2 and 3-3 list many chemical elements and ions that have been found in tailings piles. Many of these occur in tailings in only slightly higher concentrations than in background soils and also have low toxicity when taken orally (VE 78): lanthanides, including cerium, europium, lanthanum, and terbium; silicates; and zirconium, scandium, boron, gallium, and aluminum. Some other elements may be in elevated concentrations in tailings, but they too are not very toxic: copper, manganese, magnesium, cobalt, iron, vanadium, zinc, potassium, chloride, and sulfate. Some of these elements and ions will also cause water to have an objectionable taste and color well below concentration levels that are toxic to humans and animals: iron, copper, manganese, chloride, and sulfate.

Cyanide has a high oral toxicity in humans and animals, and has been found in uranium mill tailings. Once it is released to the ground, however, it is expected to be oxydized to the nitrate form, which is much less toxic (NA 77).

Other substances are both present in tailings and are regulated under the National Interim Primary Drinking Water Regulations (NIPDWR). Listing in the NIPDWR is an indication of a significant need to limit direct human consumption of these substances. The NIPDWR cover the inorganic chemicals arsenic, barium, cadmium, chromium, lead, mercury, nitrate, selenium, and silver. The toxicologies of these substances are discussed in Appendix C. Fluoride is also covered by the NIPDWR, but has not been reported as present in tailings. Molybdenum, though not included in the NIPDWR, is both toxic and present in tailings in elevated concentrations; its toxicity is discussed in Appendix C. Tailings also contain elevated levels of naturally radioactive substances, such as radium, thorium, uranium, and their decay products. Appendix C discusses both the chemical and radiological toxic effects of ingesting radium, thorium, and uranium.

Tailings are not significant sources of other toxic materials that are regulated in the NIPDWR, such as organic substances, microbiological organisms, and man-made radioactivity.

4.9 Conclusions

At many of the inactive mill sites, health risk to individuals is increased because of inhaled radon decay products (c.f. Tables 4-3 and 4-4) and gamma ray exposures from tailings. Table 4-11 summarizes the local, regional, and national risks due to radon decay products from the inactive sites. In preparing Table 4-11, we have supplemented the data presented elsewhere in this chapter with other analyses of population exposure from tailings piles (FB 76-78) so as to include all sites. All of these estimates are based on current populations and therefore will change with population growth as well as living patterns. At present, most of the potential effect is projected to occur in the regions near the inactive tailings pile. The national effect, however, is comparable.

Compared to the risk from short half-life radon decay products (see Table 4-11), the other radiological risks are much less significant. At most, they increase by 10% the risk estimated for the regional population, and the risk to the national population is much less. This incremental risk is small compared to the uncertainty--at least a factor of two--in the estimated risk for lung cancer death from the short half-life radon decay products.

The nonradioactive toxic substances present in an inactive tailings pile and their potential impact on public health and the environment must be determined for each site. Those substances which can move through ground water and which have the greatest potential toxicity include arsenic, barium, cadmium, silver, chromium, lead, mercury, molybdenum, selenium, nitrate, iron, and vanadium. In addition, among radioactive substances, uranium is most likely to be mobile in ground water, and radium and polonium are possibly mobile.

TABLE 4-11

Summary -- Risks from Radon Emitted from Tailings Piles at Inactive Sites

(Short Half-Life Radon Decay Products)

	Estimated Fatal Cancers (per 100 years)	
	Relative Risk Model	Absolute Risk Model
Deaths occurring within 50 miles of site	150	130
Deaths occurring more than 50 miles from site	90	40
TOTAL	240	170

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5: ALTERNATIVE TAILINGS DISPOSAL CONTROL LEVELS

5.1 Introduction

Generally applicable standards to protect the public health and safety and the environment must consider reasonable and feasible methods of controlling uranium mill tailings. The longevity of control methods is important, because radioactive contaminants have long lifetimes and nonradioactive contaminants are permanently toxic.

The predominant health hazard of tailings is from radon-222 released into the atmosphere. Techniques providing reasonable long-term control of radon also provide nearly complete control of particulate releases and direct gamma radiation. This chapter discusses control of radon-222 and the water pathway, and longevity of control.

The degree of radon control that we could require ranges from none (leaving the sites as they are) to nearly total (little or no radon release from tailings). The following compares three degrees of control for their costs, benefits, feasibility, longevity, and other considerations in developing an appropriate standard:

a. No control (the existing situation).

b. Radon releases controlled at various levels down to about the natural background rate.

c. Complete control (practically no release).

For potential water contamination, control alternatives similarly range from none to total. The control levels examined are:

a. No control (the existing situation).

b. Control comparable to other water quality programs.

c. Complete control (no contamination).

Ultimately, health protection will depend on the time over which controls are maintained as well as the degree. We examined the technical and economic reasonability of requiring effective control for the following periods:

a. Several hundred years.

b. Hundreds to thousands of years.

c. Longer than tens of thousands of years.

5.2 Control of Radon-222 Releases

Radon release control methods range from a simple barrier between the tailings and the atmosphere to such ambitious treatments as embedding tailings in cement or processing them to remove the radon sources. Barriers should be able to resist wind and water erosion and human intrusion. Radon control techniques and estimates for various levels of control are discussed more fully in Appendix B. A general discussion of radon control and the ancillary benefits of controlling other potential hazard pathways follows.

5.2.1 Radon Control

Radon-222 releases into the atmosphere can be controlled by covering the tailings with an impermeable barrier, like plastic, or by enough permeable material, like soil, to slow down the radon passing through so that the amount of radon released is reduced because of radioactive decay. Generally, the more permeable the covering material, the thicker it must be for a given reduction in radon release. Maintaining the integrity of thin impermeable covers over periods even as short as tens to hundreds of years, however, is highly uncertain under the likely range of chemical and physical stresses.

Natural materials can be used, such as soil, clay, gravel, or a combination. Clay-type material, especially when moist, generally resists the passage of radon much more than an equal thickness of soil or sand. The half-value-layer (HVL) is that thickness of cover material which reduces the radon release to one-half its uncovered value. Table 5-1 shows the approximate HVL of typical natural materials for reducing radon releases. These HVL values are nominal; HVLs at actual sites depend on soil composition, compaction, moisture present, and other factors.

Figure 5-1 shows nominal curves for the percentage of radon which would penetrate various thicknesses of different materials (FB 76-78). Using the HVL concept, about seven HVLs of cover reduces radon releases to less than 1% of the uncovered rate, and about 10 HVLs reduce the release to less than 0.1%. Radon reductions are multiplicative for HVLs of the same

TABLE 5-1

Nominal Half-Value-Layers of Typical Natural Materials for Reducing Radon Releases[a]

Material	HVL
Sandy, porous soil	1.0 meters
Mid-range, typical Western soil	0.5 meters
Well compacted, moist soil	0.3 meters
Moist clay	0.12 meters

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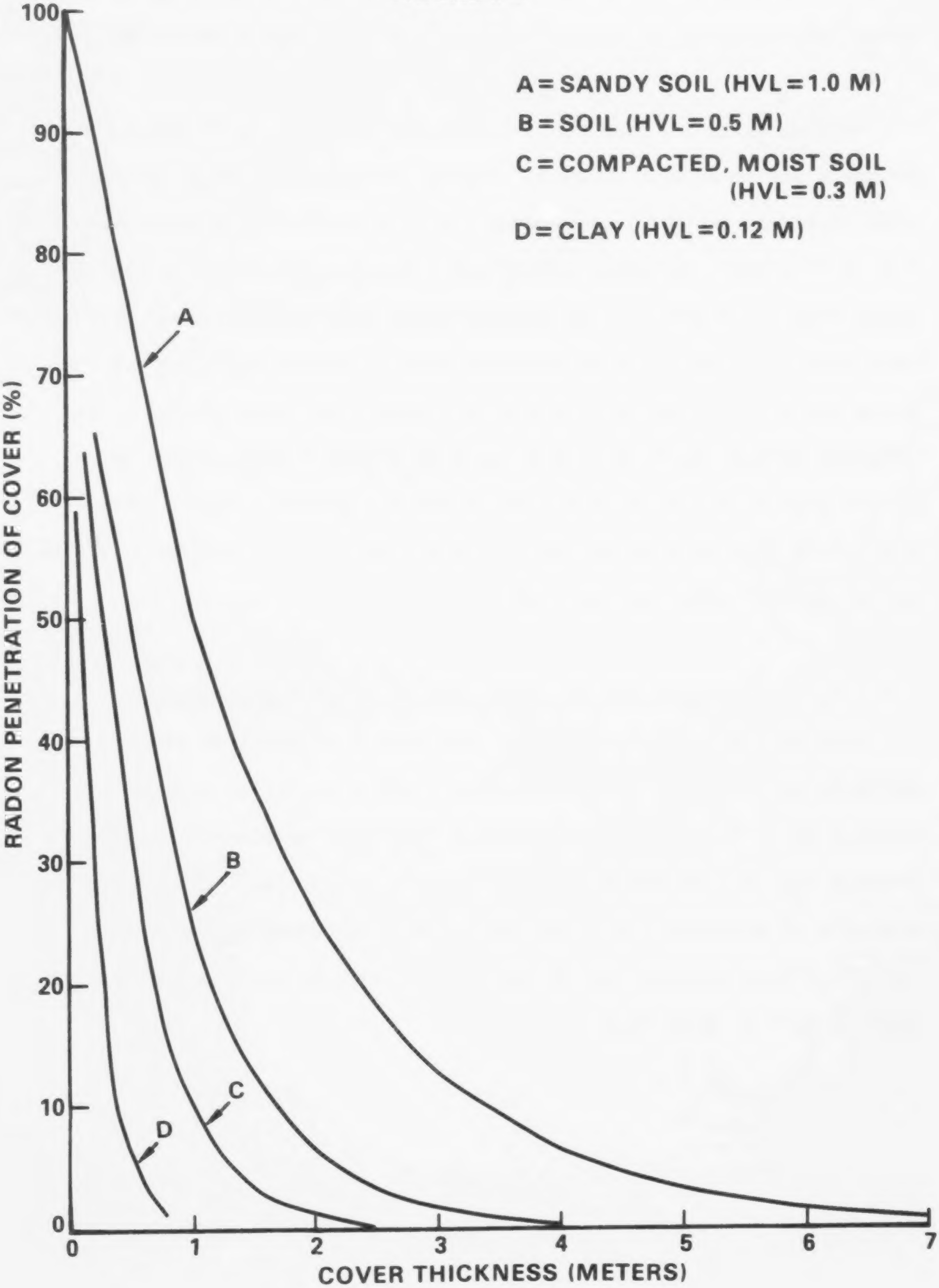
[a] From (NR 79) Appendix K, Chapter 9 and 12.

FIGURE 5-1



A = SANDY SOIL (HVL = 1.0 M)
B = SOIL (HVL = 0.5 M)
C = COMPACTED, MOIST SOIL (HVL = 0.3 M)
D = CLAY (HVL = 0.12 M)
A
B
C
D
RADON PENETRATION OF COVER (%)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
COVER THICKNESS (METERS)

or different materials. For example, one HVL of soil plus one HVL of clay reduce radon releases to 25% of the uncovered value (50% x 50% = 25%).

Uranium mills are generally located near the mines where the ore is obtained, and often other mines are nearby. Disposing tailings in these mines should be seriously considered. The thick cover and erosion protection would almost completely control radon emission for substantially longer than could generally be expected using above-grade disposal methods. Since mines are usually below the water table, however, elaborate and costly ground water protection methods might be needed, and it is not clear that effective methods are known. There will be transportation hazards and costs. Even where otherwise suitable mines are near an inactive processing site, using them for tailings disposal might make future development of the mine's residual resources impossible.

5.2.2 Effects of Radon Control on Release of Airborne Particulates

Methods that control radon will also control releases of airborne particulates. Either a thin impermeable cover or a thicker natural material cover will prevent particulates from becoming windborne. Any covering will prevent the spread of windblown tailings as long as the integrity of that cover is maintained. Therefore, assuming that some control of radon release will be required, control of airborne particulates needs no further discussion.

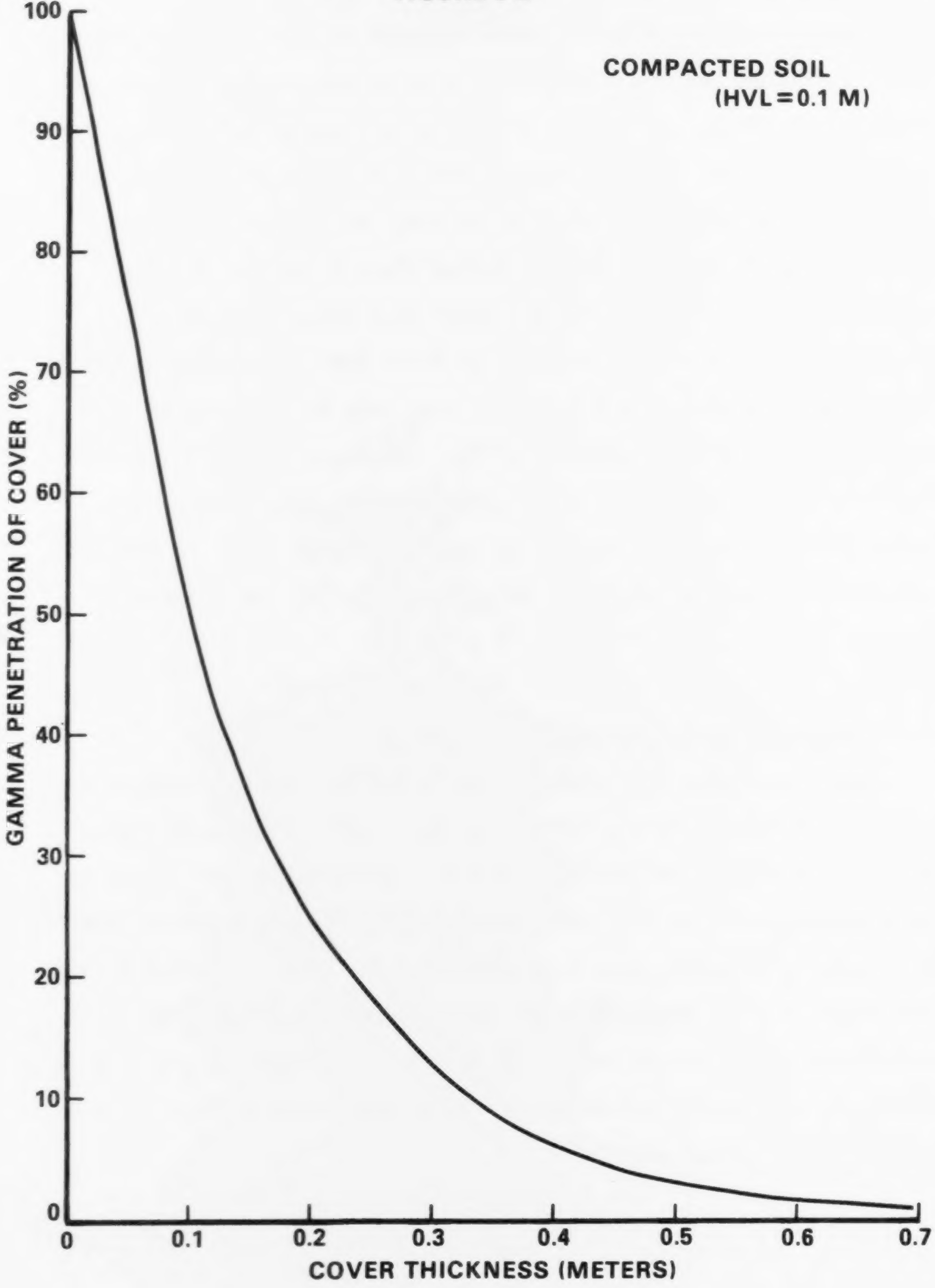
5.2.3 Effects of Radon Control on Direct Gamma Radiation

Covering tailings piles to reduce radon-222 releases will also reduce direct radiation. As with radon, attenuation of gamma radiation depends on the thickness of the cover. Figure 5-2 shows the nominal percentage of gamma radiation that will pass through a given thickness of compacted soil. The HVL of compacted soil is about 0.1 meters. Soil compaction, moisture content, type of soil, and other parameters all are factors. A thin, impermeable cover, such as a plastic sheet, will reduce gamma radiation insignificantly. A thicker cover of a material such as soil will provide significant reduction. Comparing the HVLs of soil for reduction of radon releases and reduction of gamma radiation, coverings of soil-like material thick enough to significantly reduce radon emissions will greatly reduce gamma radiation. Again, assuming that some radon control will be required, direct gamma radiation exposure from tailings piles will be addressed no further.

5.2.4 Effects of Radon Control on Potential Water Contamination

Covering uranium mill tailings piles to reduce radon-222 releases can also help to control potential contamination of surface and ground water. A cover will prevent the wind from blowing tailings directly or indirectly into surface water, and may control erosion caused by precipitation, runoff, or streams. The proper cover can reduce infiltration of precipitation into the piles. A thin, impermeable cover would prevent all infiltration, so long as the cover remained intact. A thicker cover of natural materials, especially if clay-like and shaped as a dome, might provide an infiltration barrier and encourage run-off.

FIGURE 5-2


COMPACTED SOIL
(HVL=0.1 M)
GAMMA PENETRATION OF COVER (%)
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
COVER THICKNESS (METERS)

Covering tailings below ground in specially-dug pits, open pit mines, or underground mines--can greatly help to control surface water contamination by reducing erosion. Care must be taken, however, not to contaminate useable ground water with radioactive and nonradioactive pollutants.

5.3 Control of Surface and Ground Water Contamination

A suitable cover can prevent surface water from being contaminated by windblown tailings. Control of erosion caused by streams or precipitation could consist of contouring and covering the pile and stabilizing the surface--that is, making it resistant to erosion. If necessary, the pile could be moved to a site away from existing streams and then covered. A suitable cover can reduce leaching of contaminants caused by precipitation that soaks into the pile.

Ground water contamination, caused by direct contact with the tailings and leaching of the radioactive and nonradioactive contaminants, may be the most difficult problem. There are two general approaches to limiting direct contact with groundwater. First, the tailings can be placed far enough above the water table and its predicted fluctuations to avoid contact. Second, an impermeable barrier would be imposed between the tailings and the ground water. In some cases, to make these control approaches feasible and long-lasting, the pile must be moved. Some of the existing tailings sites may already be in a suitable position above the water table. At other sites, however, continuous contact with ground water, or periodic contact as the water table fluctuates, occurs.

Ground water contaminant concentrations near the inactive mills were surveyed as part of the Phase II studies (FB 76-78), and case histories of some water contamination problems near uranium mills and mines are given in a report prepared for EPA (GE 78). There is evidence that ground water near some inactive sites is already contaminated, probably due to seepage of liquids from tailings ponds during and after their active use. Such seepage may now have slowed, because the tailings ponds at inactive sites have partially dried up. However, leaching by precipitation that infiltrates uncovered tailings piles is still a possibility.

Recent studies by Markos (MA 79) of tailings at inactive sites suggest that soluble contaminants sometimes move to the surface of the piles rather than to the ground. If confirmed, these studies would suggest that ground water contamination by long-term leaching is less likely than it might seem. The processes that carry substances upward through the piles, however, might also cause them to penetrate cover materials. If this should happen, these substances would then be carried off the site by wind and precipitation. Although the potential effects of such processes have not been assessed, contamination of surface water appears to be possible. Disposal system designers will have to consider the potential effects of such contaminant transport processes in choosing suitable disposal concepts, materials, and sites. At present, it is unclear what methods, if any, may be needed specifically to avoid harm to the environment and public health from upwardly mobile soluble contaminants.

Proper disposal of tailings piles should prevent or reduce contamination from *new* releases. However, water supplies could become contaminated in the near or distant future by toxic materials that are already on their way to an aquifer. These substances may move slowly through the ground. Ground water itself can move slower than a few feet pe year, and only in coarse or cracked materials does the speed exceed one mile per year. For these reasons, pollutants released from tailings may not affect the quality of nearby water supplies for decades or longer. However, once polluted, the quality of such water supplies cannot be quickly restored by eliminating the source of pollutants. Even if a pile is disposed of so there is no further seepage, it may take nature longer to restore the original water quality throughout the affected area than the time from the start of the pile to the first contamination of water supplies.

Toxic substances released from a pile but not yet in contact with an aquifer could be very difficult to trace and remove. A recent report prepared for EPA (JR 80) reviews methods that sometimes can improve the quality of an already contaminated aquifer. The economic and technical practicality of achieving any preset degree of cleanup is uncertain, however, especially for general application at all sites. The only feasible generally applicable control would be to monitor the quality of the aquifer and limit the use of its water. How long this may be necessary depends on the degree of contamination, the rate of ground water movement, the amount of dilution and dispersion taking place, and the intended use of the water.

5.4 Longevity of Control

The longevity or permanence of any control methods used is of prime concern. Because of the long lifetimes of the radioactive contaminants (thorium-230 has a half-life of about 80,000 years) and the presence of other toxic chemicals (which never decay), the potential for harming people and the environment will persist indefinitely. The ultimate objective of a disposal program is not only to reduce the potential hazards to an acceptable level now, but also to control these potential hazards for as long as their source persists.

This section examines the pertinent technical and social factors that influence the choice of periods for applying pollution control standards for tailings disposal.

5.4.1 Effects of Natural Forces

Natural forces may disrupt attempts to isolate radioactive waste, as several authors have discussed (EP 78, GS 78, LU 78, NE 78, GS 80). The factors affecting long-term performance are numerous and interrelated, and include some over which people may have no influence. Our general belief is that stability against natural forces could reasonably be expected for a few hundred to a few thousand years by dealing with the problem on a case-by-case basis and taking site-specific factors into account. Predictions of stability become less certain as the time period increases. Beyond several thousand years, long-term geological processes and climatic change will determine the effectiveness of most "permanent" control methods. Glaciation, volcanism, uplifting and denuding of the Earth's surface, and deposition of material have occurred during the past 100,000 years and will continue.

In a report for Argonne National Laboratories, "Evaluation of Long-Term Stability of Uranium Mill Tailing Disposal Alternatives" (NE 78), Nelson and Shepherd considered the impact of natural phenomena, including earthquakes, floods, windstorms, tornadoes, and glaciers. These events could disperse the tailings, making possible chronic exposure to their radioactive and nonradioactive toxic constituents. The following comments are summarized from their report.

5.4.1.1 Earthquakes

Earthquakes can damage caps and covers, as well as disrupt barriers under disposal sites. The number and magnitude of past earthquakes in an area suggest the probability of earthquakes in the future. As with any natural phenomenon, the confidence in such predictions rises as the time period for which reliable earthquake and faulting information is available increases. The likelihood that controls will fail because of an earthquake depends on the chance of an earthquake greater than that in the design model. Even if a disposal plan is designed on the basis of the maximum credible earthquake, there is always the chance of a larger one. If an earthquake occurs at a site, the likelihood that controls will fail will generally be high. The quantity of tailings released, however, may be small.

5.4.1.2 Floods

Flooding can result from large rainstorms, rapidly melting snow, or local cloudbursts. The erosion floods cause can impair tailings control. Increased soil moisture from flooding may also make slopes unstable and lead to landslides. Flooding frequency and the "maximum probable flood" are predictable from historical stream flow data and hydro-meteorological data. Over extremely long time periods, however, even the maximum probable flood can be exceeded. With changes in climate, the frequency of floods and the maximum probable flood may change. Floods are not time-dependent; two large floods can occur in successive years, though the probability is slight. The effects of floods can be cumulative if maintenance or corrective action is not employed.

5.4.1.3 Windstorms and Tornadoes

The frequency and intensity of windstorms and tornadoes are historically predictable. Such predictions, however, suffer from the same uncertainties as earthquake and flood predictions. The primary impact on tailings piles would be wind erosion of the cover or of the material itself. With a suitable cover or cap on the tailings, and protection of the surface against wind erosion, winds and tornadoes should have little effect.

5.4.1.4 Glaciation

Glaciers occur in mountain valleys and as ice sheets, such as in Greenland. Because of the magnitude of the forces associated with glaciation, no portion of a surface depository would be likely to survive even a small, relatively short-term glacier. The likelihood of continental glaciation in the Western U.S., even far into the future, is remote. No evidence exists of continental glaciation south or west of the Missouri River. Increased valley glaciation in the west is a possibility, however. Several glaciers exist high in the Rocky Mountains, and heavy glacial activity existed in the mountains as recently as 10,000 years ago. Increase in valley glaciation is likely over the long term. Previously glaciated mountain valleys are less desirable as disposal sites than nonglaciated sites, such as flat terrain or valleys created entirely be erosion. The possibility of valley glaciation should be considered in choosing surface or below-ground disposal methods.

5.4.2 Effects of Human Activity

Disruption of tailings isolation by people is also a possibility. The NRC has discussed the problem (in Chapter 9 of the DGEIS), especially the need for land use controls. Building atop a disposal site, excavating or drilling, or using the surface land for grazing and tilling could disrupt controls or accelerate natural erosion processes. It has been suggested that a disposal site should not be made more attractive to human or animal habitation than the surrounding environs, and perhaps it should be less attractive to discourage potential future occupancy (SH 78).

PL 95-604 requires that final disposal sites for residual radioactive material be owned by an agency of the Federal Government and licensed by the NRC (42 USC 7901). Such Federal responsibility should provide control of any human activity which might disrupt isolation of the tailings for as long as that responsibility is exercised. From a historical perspective, however, we should not expect institutions to perform such functions for more than a few centuries (RO 77, SC 77, EP 78a, BI 78, LU78). In its proposed criteria for management of radioactive wastes (FR 78), EPA stated that one should not plan to rely on institutional controls for more than 100 years. During the period of effective institutional control, it should be possible to detect and remedy the minor effect of natural forces, such as wind or water erosion. This should provide some assurance of continued stability against natural forces for a longer period of time. Selecting disposal sites to isolate tailings from expected habitation and land-use patterns, at remote location or deep underground locations, or both, is one way to protect against degradation and intrusion by human activity after institutional control has become ineffective.

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6: MONETARY COSTS AND THE EFFECTS OF TAILINGS DISPOSAL

This chapter presents the range of monetary costs for alternative pollutant control levels, and addresses the longevity characteristics of disposal methods, the potential environmental impact of controls, occupational hazards, and effects of the disposal program on the economy.

6.1 Estimated Costs

Cost estimates assume an inactive tailings pile whose area, volume, and weight approximate the average values for piles at 21 inactive sites. This "average" pile has a surface area of a little more than 19 hectares (190,000 square meters, or 47 acres), contains 780,000 cubic meters (1 million cubic yards) of tailings, and weighs 1.3 million short tons. The pile is shaped like a truncated pyramid with a base approximately 440 meters (1440 feet) on a side, including the embankments. The radon-222 release rate is assumed to be 450 pCi/m^2-sec. (More detail on the "average" pile is given in Appendix B.) Cost estimates for a tailings pile of different size can be scaled from the "average" pile by using the unit costs developed for individual tasks and the purchase of specific items, as presented in Appendix B. (These items include earth work, liners and caps, stabilizers, fencing, irrigation, matrix fixation, tailings transportation, discount rate, discounted value of future costs, and land costs.) The unit costs are used to estimate the costs of applying various control methods to the "average" tailings pile.

The general control alternatives considered in this EIS are:

(1) Leaving the uranium mill tailings where they are, but restricting access to the site. Particulate releases may be reduced by stabilizing the surfaces of the pile.

(2) Covering the tailings pile to control radon-222 releases, particulate releases, gamma radiation, and water contamination.

(3) Transporting the tailings to a new site, placing them in an excavated pit with a surface impervious to moisture, and covering the tailings to control radon releases, particulate releases, and gamma radiation.

(4) Transporting the tailings for deep disposal to a nearby open-pit or deep mine; or treating the tailings to remove radium (and possibly other substances, such as thorium). This option provides long-term control of radon releases, particulate releases, and gamma radiation.

Disposal costs depend on the choice of option for general control, and on the level of control within each option. For simplicity, we have computed only the highest and lowest costs for each combination of a general option and a specific radon control level. Table 6-1 summarizes these costs. (See Appendix B for the details.)

The costs shown in Table 6-1 do not necessarily represent conditions at any of the actual inactive sites, but they do cover all possible option combinations. For example, the least expensive mehtod for satisfying

TABLE 6-1

Ranges of Estimated Costs by Disposal Option and Radon Control Level for the "Average" Tailings Pile (in millions of 1978 dollars)

Disposal Option	Radon-222 Control Level (pCi/m^2-sec)						
	450	100	10	5	2	.5*	.1 and below
1. No control except							
Fencing	$.8 to 1.4						
Surface stabilization	$.5 to 3.6						
2. Cover to control radon		$ .6 to 4.3	$ .8 to 5.4	$ .9 to 5.8	$1.0 to 6.3	$1.0 to 7.0	
3. Below grade		$5.4 to 11.2	$5.8 to 12.5	$5.8 to 12.8	$6.0 to 13.3	$5.7 to 13.9	
4. Other							
Radium concentration							$69.2 to 75.7
Deep disposal							$6.9 to 57.6

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*asphalt cap used

control options 2 and 3 (for all radon control levels) assumes that vegetation will be used for surface stabilization, and that neither irrigation nor the purchase of a suitable top soil will be required. The most expensive surface stabilization method under control options 2 and 3 uses riprap, or large stones.

Radiological protection and measurements costs associated with performing disposal operations are not included in Table 6-1 or Appendix B. These cover such operations as radiological monitoring of workers, controlling pollutant releases while moving or grading a tailings pile, surveying and sampling contaminated soil, and cleaning transportation vehicles. Estimating such costs is difficult because neither the length of time that disposal operations will require nor the radiological survey and analysis procedures have been set. Based on data provided by Smith and Lambert (SM 78), however, we estimate that operational radiological procedures will add about $150,000 (1978) to the disposal costs of the "average" pile for each year disposal operations are performed.

6.2 Estimated Health Benefits

The benefits of any disposal option depend on how much the option reduces potential harmful effects, and for how long. The first option -- control limited to fencing, or surface stabilization and a fence -- would not reduce radon releases from the tailings to the air or water contamination. Controlling access to land near the pile would reduce doses only to those few people who might otherwise live or work there. Even this limited benefit would depend on institutional control and should not be expected to last for more than a few centuries.

Benefits under the second option -- covering the tailings at the existing site -- would be directly proportional to the degree of reduction in radon releases. For example, reducing an uncontrolled radon release rate of 450 pCi/m2-sec to 10 pCi/m2-sec would avert about 98% of the potential effects of radon emitted from the uncontrolled pile. Controlling radon releases to any significant degree would also prevent release of particulates and reduce direct gamma radiation to negligible levels. Suitable covers will protect surface and ground water by limiting precipitation infiltration. Each site's characteristics would determine a need for more specific water protection methods.

The third option -- moving the tailings below grade, with a liner if needed -- would specifically control potential ground and surface water hazards.

The fourth option is either acid leaching to concentrate the radium(1), which would then be disposed of using special procedures

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(1)Removal of additional radioactive materials, such as thorium and uranium, could extend the period over which radioactive hazards are controlled indefinitely.

(see Appendix B), or deep disposal of the mill tailings. In principle, this would provide the best prospect for long-term control of all the options, but its praticality is the most uncertain.

In describing these benefits, we assume the control methods will perform as expected. Table 6-2 summarizes the presumed benefits of the various control options.

6.3 Longevity of Control

The ultimate objective is to assure control for as long as the material is potentially hazardous, but we cannot reasonably expect instutional control to last for more than a few hundred years. Lasting effectiveness depends on physical disposal methods, proper consideration of site conditions, and verification of disposal performance over the short term. Beyond the period that control may reasonably be expected to endure, chance or natural events becomes the determining factor.

Estimated control costs depend more on the method than on the degree of radon control. The range of costs using different methods for a given radon control level, in other words, is greater than the range of costs for different radon control levels. The costliest methods generally would provide control for the longest periods of time. Therefore, longevity may be the primary factor in determining the actual cost of control.

TABLE 6-2

General Post-Disposal Benefits of Disposal Options

Disposal Option	Benefits of Control Radon	Particulates	Gamma Radiation	Surface/Ground Water
1. No control except fence	Minimal benefit	Minimal benefit	Minimal benefit	No benefit
2. Cover existing surface site to limit Radon Releases to: 100 pCi/m^2-sec	78% of health effects avoided	All Health Effects avoided	All Health Effects avoided	Some ancillary control through limiting precipitation infiltration
10 pCi/m^2-sec	97.8% avoided			
5 pCi/m^2-sec	98.9% avoided			
2 pCi/m^2-sec	99.6% avoided			
0.5 pCi/m^2-sec	99.9% avoided			
3. New site, below grade, with liner if needed	Same as Option 2	Same as Option 2	Same as Option 2	Same as Option 2, plus specific control of potential ground and surface water contamination
4. Deep disposal or acid leaching	100% of health effects avoided	Same as Option 2	Same as Option 2	Same as Option 3

Some disposal methods should last much longer than others. In general, the thicker the cover, the longer the control. Thin covers of artificial materials can greatly reduce radon releases but probably wouldn't last very long. Stabilizing a tailings pile's surface against wind and water erosion is a key factor in control longevity for disposal at or near the Earth's surface. Stabilization requires careful site selection and durable surface treatments. Disposal in a suitable location deep underground appears to be a better way to avoid disruption of tailings by natural events or people.

Below-grade disposal should be less subject to erosion than disposal above grade. Since all the tailings piles at inactive sites are now above grade, disposing of them below grade generally would mean choosing new locations. This would present opportunities for finding particularly suitable sites. In practice, however, conditions specific to each site can blur these distinctions. At some sites, above-grade disposal techniques may offer stability as good as that of below-grade disposal.

The longevity of any control method is difficult to quantify. Certain methods should last longer than others, but experience with all control methods is quite limited, especially considering the time that tailings will remain hazardous. We would expect above-grade disposal to be effective for hundreds to thousands of years; below-grade disposal, thousands of years; and deep disposal, tens of thousands of years or more. Since longevity can only be described in broad terms, it is impossible to relate the costs of specific long-lasting control methods directly to estimates of the adverse health effects they will avoid. The goal, however is to isolate tailings for as long as may reasonably be done, avoiding future harm at least for that period.

6.4 Environmental Impacts of Controls

Cleanup, transportation, and final disposal of tailings will have an adverse effect on the environment. Excavating and hauling tailings, for example, may increase airborne particulates, though attention to control of dust will reduce the problem. Radon-222 releases might also rise temporarily as tailings are uncovered or piled in a new physical arrangement. Surface runoff and other natural forces may increase erosion. Tailings or other contaminated materials will probably spill, and good housekeeping practices will be needed to assure they are cleaned up and not spread around the environment.

Cleanup of contaminated land will require hauling material to a disposal site, increasing road traffic, dust, noise, fumes, and the possibility of accidents. Moving tailings to a new location will incur similar risks. Disrupting vegetation at a new site, or obtaining material to cover the tailings, produces an adverse impact.

All of these effects will be temporary. Compared to the long-term impact of uncontrolled tailings, these temporary effects, if reduced as much as is practical, could be considered negligible.

6.5 Occupational Hazards

The workers who carry out the tailings controls will face hazards. Workers who clean and move uranium tailings will be exposed to more gamma radiation and radioactive airborne particulates than most other workers in earth moving occupations. Normal health physics procedures to control radiation and exposure will have to be employed (HA Ip). Hazards from trucks and other earth-moving equipment will be similar to those from any large-scale earth-moving project. Any occupational hazards will be temporary, and can be considered negligible compared to the long-term impact of uncontrolled tailings.

6.6 Local Economic Considerations

The possibility of economic gains to communities near the tailings sites offsets the temporary adverse environmental impacts and occupational hazards to an extent. The cleanup activities may provide temporary jobs to unemployed workers. Local business activity may increase. The community may gain the use of previously contaminated land and structures. The disposal sites, however, will be licensed by the NRC, which may limit or prohibit their public use. Since public funds spent to control tailings will be unavailable for other uses, local economic gains may be offset by dampening of other national economic sectors.

References for Chapter 6

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(SM 78) Smith, C. Bruce and Lambert, Janet A., June 1978, "Technology and Costs for Cleaning Up Land Contaminated with Plutonium," in "Selected Topics: Transuranium Elements in The General Environment," U.S. Environmental Protection Agency, ORP/CSD-78-1.

7: CONSIDERATIONS FOR CLEANUP OF CONTAMINATED LAND AND BUILDINGS

7.1 Introduction

Because land areas have been contaminated by wind- and water-borne tailings, tailing disposal will include disposal of some contaminated soils. If the control method chosen for disposal of a tailings pile requires moving it, contaminated soil beneath the pile must also be disposed of.

Buildings, too, have contaminated, by tailings carried by wind and water and used as fill under and around the structures. Buildings once part of the mill operation are also contaminated to various degrees.

7.2 Off-Site Contamination

Sec. 3.4 discussed a study to locate tailings in communities near inactive processing sites. Table 3-5 indicates that of 22,213 radiation anomalies (a gamma radiation level higher than normal) detected in the regions surveyed with a mobile gamma radiation scanner, 6,518 of these were traced to uranium mill tailings, 7,889 to other radioactive sources (including luminous dial alarm clocks and mined uranium), and 955 to naturally occurring radioactivity; 6,851 anomalies were of unknown origin (OR 73).

These data include Grand Junction, Colorado, where, because tailings were used on a large scale in construction, a Federal/State remedial action program for affected buildings is underway. In Mesa County, where Grand Junction is located, over 25,000 locations had been screened as of October 15, 1978, to identify possible tailings (GJ 79). More than 6,000 locations had some tailings on the property; the rest had none. Of the locations with tailings, about 800 are expected to receive remedial action, 200 more qualify for remedial action but the property owners probably will not apply, and the approximately 5,000 remaining have radiation levels below the program criteria for remedial action. In Mesa County tailings also were used to build sewer and water lines, streets, and other projects, which will be eligible for remedial actions under PL 95-604.

Gamma radiation surveys established the extent of contamination near the inactive processing sites from wind and water erosion of tailings piles (Table 3-6). More than 5,000 acres had gamma radiation above the normal background had gamma radiation above the normal background level. The area with gamma radiation levels equal to or greater than 10 uR/hr above background is more than 2,000 acres. This figure omits the surface areas of the tailings piles themselves, about 1,000 acres.

The seriousness of off-site contamination depends on the degree of contamination and the potential exposure to people. The amount of land and number of buildings that will require cleanup will be determined by the cleanup standards selected.

7.3 Potential Hazards of Off-site Contamination

The greatest hazard posed by tailings on open lands is their potential to increase levels of radon decay products in buildings. Exposure to direct gamma radiation and contamination of drinking water and food may also occur, but generally will be of less concern.

There is a health risk associated with radon decay products. Their concentration in an existing or future building will depend on the radium concentration in the soil under or adjacent to it. So many other factors affect the indoor radon decay product concentration, however, that establishing a useful correlation with the radium in soil is difficult. Nevertheless, Healy and Rogers (HE 78) have anaylzed exposure pathways due to radium in soils, whether occurring naturally or as contamination. They argue that one might expect indoor radon decay product concentrations of 0.01 WL for soils with radium concentrations of 1 to 3 pCi/gm to a depth of one meter or more. NRC estimates (NR 79) that 3 to 5 pCi/gm of radium can cause indoor concentrations of 0.01 WL. Both of these calculations are approximations, but radium concentrations near the lower end of these ranges correspond to common natural soil conditions. Therefore, where indoor radon decay product concentrations are only slightly elevated, tailings may not be the dominant cause, so remedial action for tailings may have little beneficial effect. Moreover, cleaning contaminated open land will not eliminate elevated radon decay product levels in future buildings, though it generally will reduce the frequency with which they occur.

Tailings also emit gamma radiation, which can penetrate the body from the outside. We expect that the indoor radon decay product concentration standards generally will be met by removing tailings from the building, and this will eliminate any indoor gamma radiation problem. For some buildings, however, removing the tailings completely may be impractical (more for engineering reasons than for cost). Alternatives, such as air cleaning, improving ventilation, or applying sealants to the walls and floors, are available. If these are used, standards will be needed to limit gamma radiation exposure of the occupants.

Natural or contaminated soils with radium concentrations of 5 pCi/gm through a depth of several feet can have gamma radiation exposure rates of about 80 mR/yr (NC 76). Exposure rates are proportionately higher or lower for other radium concentrations, and decrease as the layer of radium-containing material becomes thinner or is covered over by other materials. The potential for causing elevated indoor radon decay product levels in future buildings on such soils also depends on these factors. Therefore, cleanup standards for open land should consider both the radium concentration and the thickness of the contaminated soil.

Each gram of natural uranium contains 330,000 pCi of U-238 and 15,000 pCi of U-235. Because it appears in relatively small proportion, U-235 and its radioactive decay products usually may be ignored in evaluating the hazard of uranium tailings. The dominant hazard from most tailings is from decay products of U-238, including radium-226 and its decay products. Other radioactive substances in the tailing will ordinary pose much less risk to health than that from radium-226.

The total protection that a standard based on radium-226 provides depends on the extent to which radium has been separated from other radioactive substances, such as thorium and the U-235 decay products, during ore processing. If significant separation occurs, radium-226 concentration in the residual material may not adequately measure the radiation hazard. For example, thorium separates from radium in uranium mills using the acid leach process. Although thorium-230 and radium-226 occur in ore in about equal amounts of radioactivity, thorium compounds are more soluble in acid. Therefore, thorium radioactivity concentrations in the wastewater may be thousands of times higher than for radium, and more thorium may then seep through the pile to the soil below (RA 78). However, chemical interaction of thorium with the soils should retard further movement (GS 80).

At least one of the processing sites covered under Public Law 95-604 (Canonsburg, Pa.) may have tailings containing higher than usual proportions of U-235 decay products. Although little is known about the environmental pathways and biological effects of these radionuclides, site-specific information on their concentrations suggest that they are unlikely to be a determining factor in cleanup decisions (DO 78). The U-238 decay products are present in greater amounts.

7.4 Remedial Actions and Costs

The only remedial action that would eliminate the hazards from contaminated land and buildings would be to remove uranium mill tailings from under and around buildings and from open land, and to dispose of them along with the tailings pile. The cost and complexity of removing tailings from buildings depends on the amount of tailings and their location relative to the structure. Tailings used as backfill around the outside of a foundation, for example can be removed easily at relatively low cost. Removing tailings from under a floor or foundation, on the other hand, entails breaking up concrete to reach the tailings, a costlier and more complex procedure. In 1972, Congress enacted PL 92-314, authorizing remedial action for buildings in Grand Junction, Colorado, affected by that community's extensive use of tailings in construction. Experience gained through seven years of that program illustrates the remedial action costs that may be incurred for similar situations in other places under PL 95-604. In the Grand Junction remedial action program, the average cost to treat a residential structure has been about $13,500, ranging from $540 to $41,000 (GJ 79). Treatment of commercial structures averaged about $38,500, ranging from $6,600 to $107,000. Schools averaged about $92,900, ranging from 19,000 to $500,000. The total cost in Grand Junction through September 30, 1978, was almost $7 million. The final cost for about 800 buildings may total about $17 million (GJ 79).

For the lands and buildings included in the Phase II study, estimated cleanup costs for off-site contamination were about $7 million (FB 76-78), and for the Canonsburg, PA., area were about $3.4 million (FB 79). Because the Phase II estimates were based on interim cleanup criteria (for an engineering assessment), they may indicate only the approximate costs under a final standard.

7.5 Previous Standards for Indoor Radon Decay Product Concentration

Government agencies of the United States and Canada have previously published remedial action criteria for radon decay product concentrations in buildings.

The U.S. Surgeon General's 1970 remedial action guidance for Grand Junction, Colorado, applies to buildings on or containing uranium mill tailings (PE 70). EPA's guidance to the State of Florida applies to buildings on radium-bearing phosphate lands (FR 44). Each set of guides has two levels: 1) Radon decay product concentrations above the upper level require action; 2) those below the lower level do not; 3) between these levels, local factors determine the action required.

The Surgeon General's Guides are implemented in the Department of Energy's regulations for remedial action at Grand Junction, Colorado (10 CFR 712). In effect, they adopt the lower level as an action level for schools and residences, and the midpoint between the lower and upper levels as an action level for other buildings. This difference in action levels recognizes that children should have added protection, and that people occupy residences and commercial building for different periods. For radon decay product concentrations these actions levels are 0.01 WL and 0.03 WL, respectively, above background. The average background indoor radon decay product concentration determined for use in the Grand Junction remedial action program is 0.007 WL.

The Canadian cleanup criteria (AE 77) and the EPA recommendations for residences on phosphate lands in Florida require remedial action for indoor radon decay product concentrations greater than 0.02 WL (including background). The EPA guidance further recommends that concentrations below 0.02 WL be reduced further recommends that concentrations below 0.02 WL be reduced as low as can be reasonably achieved. Reductions below 0.005 WL above the average normal background (for nearby lands in Florida) of 0.004 WL are not generally justifiable in the Florida phosphate lands. For Florida, then, EPA has in effect recommended remedial action above 0.2 WL: stated that action is generally unjustified at concentrations less than 0.009 WL; and left action at intermediate levels to the judgment of local officials.

Surveys have been conducted to find buildings which may be affected by tailing for which remedial actions may be conducted under PL 95-604. These surveys show a variety of affected structures, whose elevated radiation levels have several different causes. The total number of buildings that will be eligible under PL 95-604 is not fully established, but we believe they are fewer or comparable in number to those in Grand Junction, that is, several hundred.

7.6 Normal Indoor Radon Decay Product Concentrations

The indoor radon decay product concentration of a building affected by tailings is the sum of contributions from tailings and from the natural environment. These contributions cannot be distinguished from one another. Knowledge of the characteristics of radon decay product concentrations in normal buildings is very useful in eciding the best form for a remedial action standard and in choosing a practical action level.

The most complete studies of normal indoor radon decay product concentrations in the United States were performed on buildings in Grand Junction, Colorado (PE 77), New Jersey and New York (GE 78), and Florida (FL 78). The samples and measurement techniques of these studies are not exactly comparable, however. The New Jersey-New York buildings studied were residences, mostly single-family one-or two-story buildings. The Grand Junction sample was mainly houses, about half of which had basements (CO 79). The reported Grand Junction data are for the lowest "habitable portion" of the building. The Florida sample is single-family houses without basements.

Some results from these studies are summarized in Table 7-1. In all cases, the reported concentrations are the average of measurements taken over a year. The data indicate wide variations in normal indoor radon decay product concentrations within each sample, even for a relatively uniform sample of buildings. Furthermore, the New Jersey-New York data show that concentrations at ground level are about half of those in the basement. (An unpublished analysis of the Grand Junction data shows a similar effect (CO 79).)

Many buildings in the western United States, where most of the sites covered under PL 95-604 are located, have basements. For

TABLE 7-1

Average Annual Radon Decay Product Concentrations in Normal Buildings

Grand Junction, Colorado(a)

Sample: 29 buildings, mostly houses, about half with basements.
Range: 0.002-0.017 WL
Median: 0.007 WL
Above 0.01 WL: 30%
Above 0.015 WL: 10% (approx.)

New Jersey-New York(b)

Sample: 21 houses, mostly single-family with full basements.

	Cellar	First Floor
Range:	0.0017 - 0.027 WL	0.0017 - 0.013 WL
Median:	0.008 WL	0.004 WL
Above 0.01 WL:	40%	8%
Above 0.015 WL:	20%	2%

Florida(c)

Sample: 28 single-family residences, without basements.
Range: 0.001 - 0.012 WL
Median: 0.0035 WL
Above 0.01 WL: 3%
Above 0.015 WL: 0%

(a) References (PE 77) and (CO 79).

(b) Reference (GE 78).

(c) Reference (FL 78).

these buildings in particular, the most important conclusions we draw from these studies are the following:

1. Normal indoor radon decay product concentrations vary greatly.

2. Concentrations greater than 0.01 WL in a useable part of a normal building are commonplace.

3. Though less common, normal concentrations greater than 0.015 WL are not rare.

7.7 Practicality of Alternative Remedial Action Standards for Buildings

Experience in the Grand Junction program aids in estimating the scope of a cleanup program for tailings under alternative remedial action criteria. Table 7-2 gives the Grand Junction program's results (CO 79) for buildings having tailings for which radon decay product measurements have been made. For residences and schools, the remedial action level is 0.01 WL above background. Among the 463 residences and schools sampled, 217 were eligible for remedial action. If the action level had been 0.005 WL rather than 0.01 WL the number eligible would have risen to 278, a 28%.

Table 7-2 also shows that 60 residences and schools have been treated but not yet brought below the action level. Had the action level been 0.005 instead of 0.01 WL above background, 111 rather than 60 would need further remedial work.

TABLE 7-2

Experience with Grand Junction Remedial Action Program[a][b]

	Total	Number Above 0.01WL + Background	Number Between 0.005WL and 0.01WL Above Background
Non-eligible			
Residences and Schools	246	0	61
Other	76	40	12
Post-remedial			
Residences and Schools	217	60[c]	51
Other	35	17	9

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[a] Modified from reference (CO 79).

[b] Table entries are numbers of buildings having tailings for which radon decay product measurements have been made.

[c] Buildings for which remedial actions have not been completed.

Table 7-2 shows that 40 or 52 additional buildings other than residences and schools would have been eligible if the action level for them had been 0.01 WL or 0.005 WL above background, respectively, rather than the 0.03 prescribed. This is an increase of 114% or 149%, respectively, in the program for that category of buildings. The table also shows that at the lower action levels additional work would be needed for 17 to 26 of the buildings other than residences and schools on which remedial action has already been performed.

References for Chapter 7

(AE 77) Atomic Energy Control Board of Canada, "Criteria for Radioactive Cleanup in Canada," Information Bulletin 77-2, April 7, 1977.

(CO 79) Colorado Department of Health, October 3, 1979, Letter from A. Harold Langner, Jr., and subsequent conversations.

(DO 78) Department of Energy, Report No. DOE/EV-0005/3, April 1978.

(FB 76-78) Ford, Bacon, and Davis, Utah, Inc., "Phase II-Title 1, Engineering Assessment of Inactive Uranium Mill Tailings," 20 contract reports for Department of Energy Contract No. E(05-1)-1658, 1976-1978.

(FB 79) Ford, Bacon, and Davis, Utah, Inc., July 1979, "Engineering Evaluation of the Former Vitro Rare Metal Plant, Canonsburg, Pennsylvania" and "Engineering Evaluation of the Pennsylvania Railroad Landfill Site, Burrell Township, Pennsylvania."

(FL 78) Florida Department of Health and Rehabilitative Services, "Study of Radon Daughter Concentrations in Structures in Polk and Hillsborough Counties," January 1978.

(FR 44) Federal Register 44, p 38664-38670, July 2, 1979.

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(GJ 79) Grand Junction Office, February 1979, "Progress Report on the Grand Junction Uranium Mill Tailings Remedial Action Program," U.S. Department of Energy Report DOE/EV-0033.

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(HE 78) Healy, J.W., and Rodgers, J.C., October 1978, "A Preliminary Study of Radium-Contaminated Soils," Las Alamos Scientific Laboratory Report No. LA-7391-Ms.

(NC 76) National Council on Radiation Protection and Measurements, December 1976, "Environmental Radiation Measurements," NCRP Report No. 50.

(NR 79) U.S. Nuclear Regulatory Commission, April 1979, "Generic Environmental Impact Statement on Uranium Milling," Volume II, App. J, NUREG-0511.

(OR 73) Office of Radiation Programs, March 1973, "Summary Report of the Radiation Surveys Performed in Selected Communities," U.S. Environmental Protection Agency.

(PE 70) Letter by Pau J. Peterson, Acting Surgeon General to Dr. R.L. Cleere, Executive Director, Colorado State Department of Health, July 1970.

(PE 77) Peterson, Bruce H., "Background Working Levels and the Remedial Action Guidelines," in the Proceedings of a Radon Workshop, Department of Energy Report No. HASL-325, July 1977.

(RA 78) Rahn, P.H., and Mabes, D.L., "Seepage from Uranium Tailings Ponds and its Impact on Ground Water," Proceedings of the Seminar on Management, Stabilization, and Environmental Impact of Uranium Mill Tailings, July 1978, the OECD Nuclear Energy Agency.

8: SELECTING THE PROPOSED STANDARDS

In PL 95-604, the Congress stated its findings that tailings "may pose a potential and significant radiation health hazard to the public" and that "every reasonable effort should be made to provide for stabilization, disposal, and control in a safe and environmentally sound manner of such tailings in order to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards from such tailings." The Environmental Protection Agency was directed by Congress to set "standards of general application for the protection of the public health, safety, and the environment" for such materials. The legislative record also shows that Congress intended that these standards apply to all sites rather than be site-specific.

The Committee report on the Uranium Mill Tailings Radiation Control Act expressed the intent that the technologies used for remedial actions should be effective for more than a short period of time: "The Committee does not want to visit this problem again with additional aid. The remedial action must be done right the first time" (House of Representatives Report 95-1480, Part 2).

Our proposed standards (Appendix D) are meant to ensure a long-lasting solution.

8.1 Disposal Standards

Our analysis of the health effects from tailings piles shows that they are mainly caused by radon emissions into the air. Environmental contamination also can occur if toxic chemicals from tailings enter surface or underground water, though this depends strongly on individual site characteristics.

8.1.1 Radon Standard

From our analysis of health effects of tailings piles, we conclude that:

a. Lung cancer caused by radon's short-lived decay products is the dominant radiation hazard from untreated uranium mill tailings piles on local, regional, and national scales. Effects of long-lived radon decay products, of windblown tailings, and of direct gamma radiation from the piles are much less significant.

b. Individuals near a pile bear much higher radiation risks than those far away. We estimate, for example, that individuals continuously living one mile from a large pile would have about 200 times as great a chance of a fatal lung cancer (7 in 10,000 versus 3 in 1,000,000) caused by radon products from the pile as would individuals living 20 miles away (Table 4-2). At some of the piles, where people live even closer than one mile, the increased risk of developing lung cancer over a lifetime is as high as 4 chances in 100 (Table 4-3).

c. The total number of cancer deaths that a pile would induce depends strongly on the size and locations of the local populations.

d. Based on recent population data, all the 22 piles at inactive sites we studied taken together may cause 40 to 90 deaths from lung cancer per century among persons living 50 miles or more away from a pile. When local and regional rates are added to these, the estimated total national effect of all the 22 piles is about 200 premature deaths from lung cancer per century, or an annual rate of about two deaths.

Part of the uncertainty in these estimates results from necessary approximations in estimating the environmental radiation levels a tailings pile produces, and the doses people will receive. Additional uncertainty comes from our incomplete knowledge of the effects on people of these generally low exposures.

Our estimates are based upon current population sizes and geographical distributions. Overall increases in national population would raise the estimated national effects in approximate proportion. Development of new population centers near currently remote piles, and substantial growth of cities already near one, would increase these estimates proportionately.

Unless radon emissions from the tailings piles covered under Title I of PL 95-604 are greatly reduced, they might prematurely kill about 200 people per century into the indefinite future. Even for piles remote from population centers, equity for people living nearby and the possibility of future development near the sites argue for control measures. A reasonable effort to prevent or minimize radon emissions from piles is required under PL 95-604.

Methods for controlling radon emissions from piles are available. The most straightforward methods call for burying the piles or covering them with appropriate combinations and thicknesses of soils, and with erosion-resistant surfaces. We believe the basic capabilities of these methods to control radon releases, although largely untested, are understood. Other methods may also be useful (Chapter 5, Appendix B, NRC's GEIS for Uranium Milling (NR 79)).

From several perspectives, as discussed below, we find it reasonable to reduce radon emission rates from tailing at inactive processing sites from current values of several hundred pCi/m^2-sec to a range more characteristic of ordinary land. Typical natural emission rates are from 0.5 to 1 pCi/m^2-sec, with variations up to several times these values not unusual (NR 79).

Next, the form and numerical values of the standard must be fixed. Three quantities will be considered as alternative basic units for the standard: the radon release rate per unit area (expressed in pCi/m^2-sec), the total radon release rate (pCi/sec, or Ci/yr), and the dose or exposure of actual or hypothetical individuals or populations (mrem/yr, person-rem/yr, person-WLM, etc.).

We rejected a dose or exposure standard. It is cumbersome to implement, with no compensating advantages except that it relates directly to risk. One major purpose of the standard is to guide the design of disposal systems. A dose or exposure standard would introduce uncertainty into this process, because radon release rates must be known before dose or exposure can be estimated.

We also rejected a standard based on the total radon release rate. Limiting the total radon release rate fails to take account of the great differences in radioactivity among the piles (see Table 3-1). A single limit on total radon release from all piles could place unreasonable burdens on the disposal designs. A limit on release rate per unit area, however, may readily be applied uniformly to all sites. Release rate per unit area is also the most meaningful quantity for comparing the emission of a site with that of normal land. Since radon release rates change with the climate, however, the standard should address the average rate over a year's time.

After considering the alternatives (see below) we have concluded that the numerical limit on pile emissions, following disposal, should be from about 0.5 to 2.0 pCi/m^2-sec. When added to the radon released from a normal earth covering, the disposal site emission rate would still be within a normal range.(1) The risk for people living or working away from the disposal site is a minor factor in choosing a standard within this range, since 98% or more of their exposure to radon comes from other sources (NR 79).

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(1) A covering of average soil will contribute an additional 0.5 to 1.0 pCi/m^2-sec.

Disposal sites generally will be large enough for small communities to be built upon. It appears unlikely that a combination of emission, residency, and construction factors would materialize that would create a public health problem under a standard in the radon emission range we are considering. The incremental risk associated with the choice of a control level within this range appears small enough so that other factors should also be considered.

Figure 5-1 shows that to control radon emissions by covering piles with soil, the required covering thickness rises sharply(1) near a rate of about 1 pCi/m^2-sec. These curves are based on theory and laboratory tests; there has been no opportunity to test them against full-scale field experience. If soil coverings should be less efficient in controlling radon than the curves indicate, meeting a standard at the low end of the radon emission range could be much more difficult and expensive than we estimate. The gain in health benefit, moreover, would be marginal. We therefore propose to allow a tailings release rate of 2 pCi/m^2-sec rather than a slightly lower figure, to allow for more technical flexibility in implementing the standard.

We considered setting a higher or lower radon release standard. Higher levels, from 10 to 40 pCi/m^2-sec, perhaps, appear unjustified; such emission rates can be lowered to 2 pCi/m^2-sec for about 10 percent additional cost.[1] With such elevated radon emissions, the probable need for land-use restrictions adjacent to the disposal site would place a continuing administrative burden on future generations.

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(1)Reducing emission from 10 to 9 pCi/m^2-sec (a 10% reduction) requires about 1cm of added soil; the same size emission reduction from 2 to 1 pCi/m^2-sec takes about 50 cm of added soil.

We also find near total control of radon release from the tailings unjustified. Incremental costs for achieving emission rates lower than 2 pCi/m^2-sec rise faster than emissions drop, and any achievable health benefits would be extremely expensive. Restricting land use near the disposal site because of radon releases from the tailings is unneeded for radon emission levels near 2 pCi/m^2-sec. We have found no administrative or esthetic advantages in further reductions.[2]

The proposed standard typically would reduce radon emissions and their possible effects by 99%. Measures that will cut down radon emissions this much for at least one thousand years (see Section 8.1.5) will also eliminate blown tailings and excess gamma radiation. Therefore, implementing the radon control standard will virtually eliminate all the potential hazards except water pollution.

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[1] This assumes that covering the tailings with soils and clay is a feasible method for radon control to an emission level of about 2 pCi/m^2-sec. Tailings piles vary widely in their size and radioactivity content. Therefore, costs of applying the burial method or any other adequate disposal technique will vary greatly among the piles. We estimated potential disposal costs for a variety of methods (see Chapter 6 and Appendix B). For example, assuming the tailings would be taken to a new site and buried in a shallow pit, we estimated the disposal cost for an average pile as 6-13 million dollars (1978). Costs for some piles may be partially offset by the value of residual uranium that may be recovered by reprocessing the tailings before disposing of them, or the reclaimation value of the original tailings site.

[2] However, PL 95-604 provides that after remedial actions are completed, the tailings will be in Federal custody under license by the Nuclear Regulatory Commission.

8.1.2 Ground Water Standard

Since most of the inactive sites are in dry climates, much of the water that may ever infiltrate them has probably already done so during active operation of the mill. This probably is not true for all sites, and standards for protecting ground water after disposal of the tailings are needed.

Under the proposed ground water standards (Appendix D), after a tailings pile is disposed of, it may not cause the concentrations of certain pollutants in an underground source of drinking water to either (1) exceed the contaminant level specified for that pollutant, or (2) increase, where the background concentration of the pollutant already exceeds the applicable specified contaminant level. An underground source of drinking water is defined as an aquifer currently supplying drinking water for human consumption, or an aquifer in which the concentration of total dissolved solids is less than 10,000 milligrams per liter (FR 79).

The proposed ground water protection standards could be considered too strict if implementing them would be unreasonably costly or if they would be impossible to apply. Information available suggests that our proposals are practical. The following sections discuss alternative approaches to setting the standard, and describe the reasons for choosing the proposed standards.

Approach to Ground Water Protection

These standards are conditions for disposal of uranium mill tailings from inactive processing sites, not ambient water quality criteria. We have concluded that disposal of tailings should not degrade ground water beyond levels that retain its fitness for direct consumption by people. We recognize that ground water quality is also important for other reasons; its effect on fragile ecosystems, for example, and irrigation. Other standards may be appropriate to protect its usefulness for these other purposes. We believe, however, that the prevention of adverse human health effects from direct consumption of ground water should be foremost among several objectives in protecting ground water quality.

Contaminants of Concern

Contaminant levels in the National Interim Primary Drinking Water Regulations (NIPDWR) provide the best current guidance of adequate protection levels for drinking water. However, we also considered whether the NIPDWR cover all contaminants found in tailings, or contaminants that are not.

Except for fluorides, all the inorganic chemicals listed in the NIPDWR have been reported as present in tailings.(1) However, uranium mill tailings are not significant sources of organic chemicals, microbiological contamination, or man-made radioactivity, so these categories of the NIPDWR can be disregarded.

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(1) These inorganic chemicals are arsenic, barium, cadium, chromium, lead, mercury, nitrate, selenium, and silver. Radium and thorium are subject to radioactivity limits in the NIPDWR.

Other substances possibly harmful to human health were not included in the NIPDWR due to their relative rarity in drinking water systems, the lack of analytical methods, the high costs of monitoring, or the lack of toxicity data. Several such substances are present in leachate from tailings. We have reviewed these substances (see Sections 4.8.2 and 4.8.3) and have included two -- molybdenum and uranium -- in our proposed standards, because of the seriousness of their toxic effects on humans, animals, or plants, their abundance in the tailings, and their expected environmental mobility.

We have also considered the contaminants addressed by the National Secondary Drinking Water Regulations (NSDWR). The NSDWR (40 CFR 143) represent EPA's best judgment of the standards necessary to protect underground drinking water supplies from adverse odor, taste, color, and other esthetic changes that would make the water unfit for human consumption. We decided, however, not to include the contaminants identified in the NSDWR in the proposed standards. The list of contaminants we are including covers the most hazardous substances in many different chemical forms. Conditions that control these toxic substances will also control many other substances.(1) We expect scientific analyses and predictions based upon them to be the primary means of demonstrating compliance with the standard, and do not wish to complicate that task by including nonessential requirements.

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(1) For example, because they are chemically similar to substances that are listed in the proposed standard, elements and ions such as chloride, bromide, sodium, sulfate, and ammonia are implicitly being addressed. We expect cyanide to be converted to a nitrate as it travels through the underground environment, and nitrate is listed in the standards. Many of the radioactive decay products of uranium, thorium, and radium will be controlled by controlling the parents. Uranium and radium are listed in the proposed standard; thorium is addressed through the specification for gross alpha activity.

We also considered for coverage in these standards the pollutants covered in the publication "Quality Criteria for Water" (EP 76). "Quality Criteria for Water" recommends levels for water quality according to the objectives of Section 101(a) and the requirements of Section 304(a) of the Clean Water Act. Its primary purpose is to recommend levels for surface water quality that will provide for the protection and propagation of fish and other aquatic life, and for recreation. While several health-related substances that could be present in tailings leachate are listed, the recommended limits are geared to protecting aquatic life and are not appropriate for ground water. Further, the recommended limits are written as guidance in developing standards and not as standards themselves. Therefore, we decided that this list was inappropriate for these standards.

Levels of Contamination

The proposed standards require a reasonable expectation that releases from tailings piles will not cause:

(a) The concentrations of certain contaminants in ground water to exceed specified levels, or

(b) An increase in the concentration of any of those contaminants in ground water where the existing (upstream) concentration exceeds the specified level.

The first requirement, (a), protects water that can be used as drinking water without treatment under current regulations, except that we have added coverage of molybdenum and uranium. The proposed concentration level for molybdenum is appropriate for avoiding toxic effects in humans, in accordance with the recommendations of a recent report to EPA (CH 79). The proposed standard for uranium is the level for which our estimate of bone cancer risk is about the same as the estimated bone cancer risk for radium under the NIPDWR. The second part, (b), protects ground water already at or above the maximum contaminant level, by preventing increases in contaminant concentrations.

We considered several arguments for more lenient standards than those proposed: (a) The increased disposal cost might be greater than the value of the threatened resource; (b) treating the water after contamination would be a more efficient way to remove undesirable substances; and (c) some of the allowable levels are commonly exceeded in ambient or native ground water, effectively resulting in a nondegradation standard for those aquifers.

We respond to these arguments as follows:

(a) We are not required to balance disposal costs against the value of ground water resources, nor can the "value" be determined for an indefinite future. Moreover, we do not know and probably cannot determine a useable relationship between disposal costs and specific ground water protection requirements. We believe the proposed standards are a reasonable approach to ground water protection.

(b) Treating ground water after contamination may be efficient when it is done, but undoubtedly some people will continue to use untreated water. We believe it preferable, and more consistent with the intentions of Congress, to minimize the need to treat water. Tailings piles disposed of in accordance with the proposed standard should not cause ground water "problems" for people in the future. We cannot be as sure that more lenient standards will provide adequate protection.

(c) We expect that our standards often will amount to nondegradation standards, because native levels of dissolved substances in aquifers where the piles are located are often not very low. We have no compelling reasons to allow tailings to increase these levels, however. If the native water quality itself may present problems for future users of increasingly scarce ground water resources, why should disposal of these tailings piles be allowed to worsen the situation?

Reasons we considered for adopting more stringent standards include: (a) tailings disposal is only one of several sources of ground water contamination, and each source contributes to the overall rise in contaminant levels; (b) future research may find that lower levels are necessary to adequately protect health; (c) some agricultural, industrial and other important uses of ground water may be impaired; and (d) ground water is often consumed without treatment, so more stringent standards would require less reliance on monitoring and treatment before domestic usage.

Our analysis of these reasons follows:

(a) The proposed standard does recognize that an aquifer may be polluted by several sources. Where existing ground water contaminant concentrations exceed the levels specified in the proposed standards, the disposal system should be designed not to allow contaminant levels to increase at all. Future sources of contamination, when added to releases from tailings, may cause increases in earlier concentration levels. If the resulting increases are large, however, under the standards contaminants from the tailings will not be the dominant contributors to the increases. Releases from the tailings, when added to contaminants from other sources, could be the major factor in causing small increases in concentrations, but small increases are not very significant.

(b) Since tailings are mainly the ground up residues of rock, contaminants that may leach from them into water are already present in varying degrees in native ground and surface waters. People have always consumed water containing these substances, so it appears unlikely that these substances will be found in the future to be very much more toxic than we presently believe. Further, our standards apply only to the relatively few sites covered by the Title I program of PL 95-604. Under the circumstances, any harm that might be avoided by stricter standards is both small and speculative.

(c) Our proposed standards would allow very good quality water to be slightly degraded. If and when this occurs some uses of the water might be impaired. Such impairments are speculative. In view of the limited number of sites to which the standards apply and the degree of protection they afford for good quality water, the possibility of such impairments does not appear to be a serious defect in the proposals.

(d) Our standards are designed to protect people who may directly consume the water. Whatever the standards may be, the purpose of monitoring is to determine actual contaminant levels. The extent of necessary monitoring at any site should be determined in part by considering the possibility of unexpected failures of the disposal system and other site-specific factors. It seems doubtful that stricter standards would have much influence on such decisions.

Where the Standard is Applied

Another issue regarding ground water protection is the physical point at which the standard should be applied. At what point in the aquifer, in other words, does contamination from tailings constitute noncompliance? The places we considered are the site boundary, the waste boundary, or some specified distance from the waste.

In the long-term viewpoint appropriate for uranium tailings, the concept of a site boundary should play a minor role because it only distinguishes areas that a responsible party controls from areas where the general public may be affected. Long after disposal, however, the size of the region that may be affected is much more significant.

Applying the standard to the waste boundary would minimize the affected area. However, the tailings at inactive processing sites have, to some extent, merged with their immediate surroundings, so the waste boundary may be hard to define. More significantly, a standard applied so near the waste may be difficult to meet at some otherwise adequate existing sites. Where the standards might be exceeded only in the immediate neighborhood of a pile, the cost of liners and re-siting to avoid the violation appears to be unjustified. To avoid these higher costs and their small benefits, a strict standard should apply only beyond some distance. We propose this distance to be 1.0 kilometer from the smallest practical boundary of the waste when an existing tailings site is used for disposal. A smaller distance of application might not serve our intended purpose of avoiding large expeditures for very little gain, and we believe that a much larger distance would be insufficiently protective. However, if tailings are moved to a new disposal site, for whatever reason, then new opportunities for site selection and preparation become available. For new sites we propose to apply the standards 0.1 kilometer from the waste boundary. In effect, this is as protective as applying it at the waste boundary, while allowing some benefit from sorption and dilution in immediately adjacent ground, in case small leaks occur.

Underground Drinking Water Source

The choice of the 10,000 mg/l total dissolved solids measure for usable aquifers follows EPA's general policy that ground water resources below that concentration be protected for possible use as drinking water sources. This policy is based on the Safe Drinking Water Act and its legislative history, which reflects Congressional intent that aquifers in that class deserve protection.

8.1.3. Surface Water Protection

Wind, rain, or floods can carry tailings into rivers, lakes, and reservoirs. Pollutants may also seep out of piles and contaminate surface waters. We believe that the standards should limit the effects of these processes on surface water quality. We expect that implementing the radon emission limits and the ground water protection requirements will greatly reduce the potential for contamination of surface water.(1) A pile with severely restricted radon releases will not be able to release particulates to wind or water. Similarly, the ground water protection requirements imply limited water flow through the pile, which limits flow to the surface as well as underground. Thus, implementing the radon emission and ground water standards may protect surface water. To assure adequate protection, however, we propose to require that surface water not be degraded by tailings after disposal of the piles. This means that the tailings disposal site should not cause increases in the concentration of harmful substances in surface water.

We considered banning any release of pollutants to surface water. This may be more difficult to implement than the selected standard, however, since it would require showing that not even microscopic releases will occur. Our chosen standard requires any potentially harmful contaminant streams from the tailings to have lower concentration of contaminants than the surface water they may enter. The standard applies to all harmful contaminants from tailings, and some of them are certainly present only in very low concentrations in surface water. Satisfying the standard will therefore require strict limits on releases to surface water of at least these latter substances. In practice, we expect that the means used to inhibit pollution of surface water by harmful contaminants that are already present in low concentrations will restrain the movement of most other substances as well. The standard, then, will be very protective of surface water.

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(1) However, recent studies (see Sec. 5-3) suggest that some processes occurring in tailings piles tend to carry contaminants upward, perhaps even through soil coverings. Disposal system designers must carefully consider this possibility. The Department of Energy currently is intensively investigating a variety of disposal methods.

We have chosen to apply the standard to "navigable waters" as defined in an EPA Federal Register notice (44 F.R. 32901, June 7, 1979). This definition was adopted for EPA's regulations under the National Pollutant Discharge Elimination System, 40 CFR 122.3(t). In essence, it includes all surface waters the public may travel on, enter, or draw food from. However, there is no formal relationship between EPA's standard under PL 95-604 and regulations under the National Pollutant Discharge Elimination System; either may be changed without affecting the other.

8.1.4 Remedial Action for Existing Ground Water Contamination

There is evidence of limited ground water contamination at some of the inactive sites, but the prospects for long-term contamination have not been fully assessed. The proposed ground water protection standards apply only to releases from tailings that may occur after disposal of the piles. It may sometimes be possible to improve the quality of an already-contaminated aquifer, but we believe a generally applicable requirement to meet pre-set standards is not feasible.

The Department of Energy will prepare Environmental Impact Statements or Environmental Assessment reports for each site to support the decisions it will reach, with NRC's concurrence, on necessary remedial actions to satisfy the standards. We believe that disposal methods that satisfy the standards will avoid any ground water problems caused by future releases from the piles for as long as the standards apply. We expect DOE to consider the need for and practicality of controlling contaminants that have already seeped into the ground under the tailings pile, and to apply technical remedies that are found justified. Institutional controls should also be applied. If tailings are found to be contaminating ground water that is being used, we would expect DOE to provide alternate water sources or other appropriate remedies. We note that PL 95-604 will terminate DOE's authority to do so as a remedial action seven years after we promulgate standards, unless Congress extends the period. However, Sec. 104(f)(2) of PL 95-604 provides for Federal custody of the disposal sites under NRC licenses after the remedial action program is completed. The custodial agency is authorized to carry out such monitoring, maintenance, and emergency measures as the NRC may deem necessary to protect public health. We expect NRC's requirements will be sufficient to ensure detection of any contamination by the tailings of usable ground water near the disposal sites, and to cause the custodial agency to take such measures as may become necessary to avoid any significant public health problem.

8.1.5 Period of Application of Disposal Standards

Congress recognized that uranium mill tailings are hazardous for a long time, and directed EPA to provide long-term public protection from these hazards. We propose requiring a reasonable expectation that the radon emission and water protection standards for disposal of tailings piles will be satisfied for at least one thousand years.

Any choice is partly arbitrary; there are no rules or precedents to guide the decision. Neither does scientific analysis point uniquely to one period over another.

We have concluded that it would be impractical to apply uranium mill tailings standards for periods as long as 10,000 years. Providing a reasonable expectation of compliance with the standards over such long periods, if possible at all for tailings, could be done only if they were buried several hundred feet or more beneath the surface. During such long time periods, climates change markedly and land surfaces may be denuded, severely uplifted, or otherwise considerably transformed. Deep below the surface, severe changes are likely to be more gradual and predictable. For reasons described earlier, the practicability of deep burial of uranium tailings is uncertain. Yet, if strict standards were to apply for as long as 10,000 years or more, no other disposal method would seem possible.

With tailings disposed of at or near the earth's surface it appears feasible to meet the standards for one thousand years or more. The primary threat during this period is flooding. Methods of protecting tailings against floods and other natural disruptions appear to be available. These methods, however, may not be applicable at every existing inactive site; for long-term flood protection, for example, some piles might have to be moved.

Standards applying for less than one thousand years would be easier to satisfy, and might result in some cost savings. The state-of-the-art of judging the future performance of a given disposal system does not support making fine distinctions, however. Therefore, the savings would be small unless the period of application were only a few hundred years. Institutional control methods such as recordkeeping, maintenance, monitoring, and land-use restrictions are useful adjuncts to an adequate disposal system, providing greater protection than the standards require, and regulating deliberate disruptions of the tailings by people.(1) We do not believe, however, that they should be relied upon for periods longer than a century, and are inappropriate for long-term control. Institutional control methods should not replace use of adequate long-term physical disposal methods.

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(1) For example, Sec. 104(h) of PL 95-694 anticipates that subsurface minerals at a tailings disposal site might be used. It provides, however, that any tailings disturbed by such use "will be restored to a safe and environmentally sound condition." We propose, therefore, to apply the disposal standards to the use of any subsurface mineral rights acquired under the provisions of Sec. 104(h).

We believe that one thousand years meets the Congressional criterion that "the remedial action must be done right the first time." A thousand-year standard does not mean that our concern for the future is limited to one thousand years; it reflects our judgment that the disposal standards must be practical. Based on existing knowledge of control methods and natural processes, we believe it unreasonable to generally require longer protection under this remedial program, because adequate methods for demonstrating compliance are not clearly available and may be very costly. We consider it likely, however, that the implementers of the standards will require longer protection at some piles, based on site-specific evaluations of disposal methods and their costs.

The disposal standards could be viewed as performance standards, stating conditions to be satisfied without addressing the means. Compliance could be verified by monitoring, and assured through maintenance. But fundamentally, they are design standards. They are minimum requirements that the designers of a disposal system should plan to satisfy over the full period of their application. The "reasonable expectation" for meeting the limits specified in the standards will be established by considering the physical properties of the disposal system, not by relying on institutional methods.

8.2 Cleanup Standards

8.2.1 Open Lands

The proposed standard requires that for any open land contaminated with tailings, the average radium concentration in any 5-centimeter thickness shall not exceed 5 pCi/gm after cleanup. These conditions provide a high degree of protection from tailings at inactive uranium processing sites, and are not unreasonably burdensome to implement. The protection achieved will often be greater than is apparent from the standard, since the radium concentration of any material not removed will often decrease sharply with depth. After the required cleanup, such a site will be little more hazardous than a similar area which never had a tailings pile.

Locating contaminated soils with concentrations less than 5 pCi/gm would require extensive surveys and lengthy measurement procedures. Increasingly large land areas would need to be stripped in order to lower the radioactivity much below 5 pCi/gm. Doing this would provide very little gain in health protection, since such slightly contaminated soils are usually thin layers containing little total radium. To keep sampling costs within reason, and to avoid having to clean large areas which contain little radioactivity, the proposed final standard therefore requires that for any open land contaminated with tailings, the average radium concentration shall not be more than 5 pCi/gm after cleanup. The contamination which remains after such cleanup will have less than five times the radon release of average soils. It could also cause a gamma radiation dose of below 80 millirad per year to a person who spends 100% of the time outdoors on the site. These levels of radon emission and gamma radiation are within the variations that occur in undisturbed land areas. We believe that the actual radon and gamma ray levels after cleanup will usually be much less than the maximum possible under these standards.

For contaminated material located more than one foot beneath the surface of open land, our proposed standard requires cleanup if the average radium concentration over any 15-cm thickness is greater than 5 pCi/gm. Practical measurement instruments cannot find buried material of this concentration in a layer any thinner. We expect that this standard for buried material will serve mostly to define the edges of buried tailings deposits, because the radium concentration in tailings is usually much higher than 5 pCi/gm.

In most cases, concentrations a few times higher than the proposed standard allows would cause only a slight increase in risk. Since concentration usually declines rapidly with depth, even a standard requiring removal of material until the radium concentration level reaches 10 or 20 pCi/gm would be protective. Unusual distributions of radium would be much more significant, however, and areas with 5 to 20 pCi/gm are clearly above ordinary background levels.

Surveys at inactive processing sites indicate that it should cost little more to implement the proposed standard than one permitting levels two to four times higher. The proposed standard is EPA's judgment of the most stringent cleanup condition that may reasonably be required uniformly for all the inactive mill sites.

The proposed standard addresses future as well as present hazards and uses an intrinsic property of tailings that can be easily measured. We considered other forms for the standard, such as limiting the residual surface gamma radiation, the radon release rate, or the predicted concentration of radon decay products in future buildings on the land. All these would restrict the residual hazard, but they would be harder to apply to material which has been buried and might be uncovered later.

We expect that the rules developed to implement this standard will relate the concentration of radium in soil to other conveniently measured quantities. We also expect that appropriate sampling techniques will be established to locate and identify tailings material, determine its concentration of radium, and verify compliance with the standard. Any such rules must insure that the standard is not met simply by dispersing the material to achieve a lower concentration.

8.2.2 Buildings

8.2.2.1 Indoor Radon Decay Product Concentration Standards

Exposure even to normal indoor radon decay product concentrations carries some health risk, but we believe Congress intended that people should not have to bear an unreasonable increase in this risk due to tailings. Remedial actions will be required when a building affected by tailings exceeds the levels we set as the remedial action standards. When remedial actions are finished, the level must either not be exceed, or tailings must not be the cause of any remaining excess. We believe that expressing the indoor radon decay product standard in terms of total concentration of these products is the only workable form, as the following discussion indicates.

Indoor radon decay product concentrations in normal buildings vary widely. Tailings near or under a building may be identified by gamma ray measurements, historical records, visual inspections, or specimen analysis. Because of the fluctuations in normal indoor radon levels, however, it is impossible to tell what the concentration of radon decay products would be without the tailings. Small elevations when tailings are present cannot be distinguished from normal background levels. Further, contaminated buildings vary in location, design, materials, and patterns of use, all of which affect the indoor radon decay product concentration. It is impractical to determine an expected background value for a particular building, either from measurements of unaffected buildings or by any other means.

For these reasons, an action level expressed in terms of an increment over the background radon decay product concentration cannot be implemented easily. We prefer an action level in terms of the total indoor concentration, which is directly measurable. With a fixed measurement method, this standard gives an unambiguous criterion for remedial action for any building affected by tailings.

We also considered expressing the standard in terms of the quantity or concentration of tailings near the building, or the gamma radiation they produce. There is no sure way, however, to relate these quantities to indoor radon decay product concentrations. This is a critical deficiency, because the radon products are the basic hazard.

A standard for total concentration of radon decay products provides the same action level for all affected buildings, though normal concentrations in one affected area may tend to be higher than in another. While normal indoor radon decay product concentrations vary with natural radium concentrations in soil, soil porosity, and other factors, we know of no way to take them into account in the standard. In these circumstances, we consider the regional protection inequity minor, as long as the action level we choose is within the normal range of levels in the affected areas.

We believe that the proposed remedial action level of 0.015 WL (including background) for occupied or occupiable buildings is the most protective level that can be justified for the PL 95-604 remedial action program. It is about the same as that applied to homes and schools over the last seven years in the Grand Junction remedial action program, because the action level there was 0.01 above an "average" background value taken as 0.007 WL. Experience in the Grand Junction program and studies performed by EPA for basementless homes in Florida indicate that remedying concentrations greater than 0.015 WL is usually practical in view of technical and cost considerations. In some situations, a lower action level might be justified. However, studies of normal houses with basements in Grand Junction, New York, and New Jersey indicate that about 10% or more are above 0.015 WL. We have concluded that efforts to reduce levels significantly below 0.015 WL by removing tailings would often be unfruitful, and the funds expended wasted.

Although indoor radon decay product levels exceeding 0.015 WL can occur in the absence of uranium mill tailings, these proposed standards are explicitly for remedial actions at sites designated under PL 95-604.(1) PL 95-604 is clearly directed at potential health problems due to tailings, and not to similar hazards from other causes. We are not calling for lengthy and expensive procedures to determine whether any tailings are present when the level is only slightly exceeded. Professional judgment in the field must be relied upon in such cases to implement the standards sensibly. If the allowable level is still exceeded after all apparent tailings have been removed or otherwise prevented from affecting the interior of the building, then the standard requires no further remedial measures.

8.2.2.2 Standards for Indoor Gamma Radiation

The proposed limit on indoor radon decay product concentration is based on the hazard from breathing air containing these products. Tailings also emit gamma radiation, however, which can penetrate the body from the outside. We expect that the indoor radon product concentration standards generally will be met by removing the tailings from the buildings and that this will eliminate any indoor gamma radiation problem. It is only in unusual cases that a standard for limiting gamma radiation exposure may be needed.

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(1) In particular, the proposed remedial action standard should not necessarily be taken as an appropriate design goal for indoor radon decay product concentration in new housing.

It will often be possible to meet the radon decay product standards without removing the tailings. Removal is the remedial method we wish most to encourage, however, because of its positive and long-lasting effectiveness. To this end, we propose an action level for gamma radiation of 0.02 mR/hr above background,(1) which allows a limited degree of flexibility in the methods for reducing indoor radon decay product concentrations. On the other hand, reducing the standard much below 0.02 mR/hr would virtually eliminate flexibility in remedial methods, and provide only a small additional health benefit to those few individuals who might be affected. If the occupants of the building were present 75% of the time, the proposed standard would allow gamma radiation doses from the tailings of about 130 mrad per year. This is about twice the average annual background dose from gamma rays in the regions near the piles.

8.2.2.3 Radiation Hazards Not Associated with Radium-226

The total protection that a standard based on radium-226 affords depends on the extent to which radium has been separated from other radioactive substances during ore processing. Radium-226 concentrations in the residual material may not adequately measure the radiation hazard in all cases.

For the reasons discussed in Sec. 7.3, we cannot yet say in all cases how effective cleanup standards based on radium-226 will be in controlling

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(1)Indoor background levels of gamma radiation are easier to determine and less variable than is the case for measurements of radon decay product concentration.

U-235 decay products and thorium, and we are not in a position to set a separate standard for them. It is our judgment, however, that adequate protection would be provided if, after cleanup, the total risk from all uranium and thorium isotopes and their decay products pose no greater risk than the proposed final cleanup standards allow for radium-226 and its decay products. The degree to which any particular site would need to be cleaned in order to meet this condition will have to be determined following detailed studies of tailings at that site, and further evaluation of the hazard pathways there.

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(PE 70) Letter by Paul J. Peterson, Acting Surgeon General, to Dr. R.L. Cleere, Executive Director, Colorado State Department of Health, July 1970.

9: IMPLEMENTATION

9.1 Administrative Process

Public Law 95-604 requires that the Secretary of Energy implement EPA's standards for uranium mill tailings from inactive processing sites. The Secretary or a designated party will select and perform remedial actions for designated processing sites in accordance with the standards, with the full participation of any State which shares the cost. The Nuclear Regulatory Commission (NRC) shall concur in selecting and performing the remedial actions, and affected Indian tribes and the Secretary of the Interior shall be consulted as appropriate. The Federal Government and the States will bear the costs of the remedial actions as prescribed by law.

9.1.1 Disposal Standards

The disposal standards will be implemented by showing that the disposal method can reasonably be expected to satisfy the radon emmission limits and water protection provisions of the standards for at least one thousand years. This expectation should be founded upon analyses of the physical properties of the disposal system and the potential effects of natural processes over time. Computational models, theories, and expert judgment will be major tools in deciding that a proposed disposal system will satisfy the standard. Post-disposal monitoring can serve only a minor role in confirming that the standards are satisfied. Where measurements are necessary to determining compliance, they may be performed within the accuracy of available field and laboratory instruments used in conjunction with reasonable survey and sampling procedures.

9.1.2 Cleanup Standards

The Department of Energy (DOE) will need to make a radiation survey of open lands and buildings in areas believed to have tailings, and determine whether the standards are being exceeded because of tailings. After taking remedial action to reduce radiation, compliance with the standards will have to be verified. DOE, working with NRC and the participating State, will need to develop radiological survey, sampling, and measurement procedures to determine necessary and practical cleanup actions, and to certify the results of the cleanup. We have published elsewhere the general requirements for an adequate land cleanup survey (EP 78a).

These procedures are important in making the standards effective. In view of this, we considered providing more details of the implementation as part of our rulemaking. To give more flexibility to the implementers, we chose not to do so. We believe this was warranted because conditions at the various processing sites vary widely and are incompletely known. The following clarifies our intentions and should help to avoid the unproductive use of resources that could result if the standards were interpreted so strictly that complying with them would be unreasonably burdensome.

9.1.2.1 Purpose of cleanup standards

The purpose of our standards is to protect public health and the environment. We designed them for adequate protection using search and verification procedures with reasonable cost and technical requirements. Since, for example, we intend the building cleanup standards to protect people, measurements in such locations as crawl spaces and furnace rooms are inappropriate. Remedial action decisions should be based on radiation levels in occupiable parts of the buildings. The standards for cleaning up land surfaces are designated to limit exposures of people to gamma radiation and to radon decay products in future buildings. In most circumstances, failure to clean a few square feet of land contaminated by tailings would be insignificant. Similarly, in attempting to find tailings beneath the surface on open land, reasonableness must prevail in determining where and how deeply to search. Requiring proof that all the tailings had been found would be unreasonable. In all applications of our proposed cleanup standards, search and verification procedures which provide a reasonable assurance of compliance with the standards will be adequate. Necessary measurements may be performed within the accuracy of available field and laboratory instruments used in conjunction with reasonable survey and sampling procedures. We are confident that DOE and NRC, in consultation with EPA and the States, will adopt implementation procedures consistent with our standards.

9.2 Exceptions

We believe that our proposed standards are the strictest that are justified for general application at all the inactive uranium processing sites covered by PL 95-604. However, providing greater protection may be reasonable at specific sites. We urge the implementers to lower the residual risk as far below the required level as is reasonably achievable.

In the decades since tailings at inactive sites were deposited, weather and people have created a wide range of problems. The standards may be unreasonably strict in some exceptional circumstances. If meeting the standards is impossible, or if some clearly undesirable health or environmental side effects are unavoidable, applying the standards would be unjustified. Tailings may be inaccessible to the equipment needed for their removal, or workers might be endangered in trying to remove them. In such cases, applying the standards should be reconsidered. Similarly, disturbing scarce desert vegetation and soils may be unjustifiable where the standards are only slightly exceeded.

Because the scale of material-moving activity is so great, the possibility of serious harm to both workers and the general public from accidents associated with transporting an entire tailings pile to a new disposal site deserves particular consideration. Relocating a pile should be considered whenever it may be impractical to satisfy all the disposal standards at the original location. However, circumstances might be such that one would not expect the standards to be greatly exceeded within a thousand years, and that substantial human exposure to any resulting pollution would not necessarily occur. If all practical transport methods would probably cause serious harm to people from accidents, and if this and other risks associated with the transportation system are large enough, the near-term danger may outweigh the additional long-term benefits of full rather than partial compliance with the standards. By carefully considering all these factors for each tailings pile where the issue arises, exceptions to the disposal standard could be justified because of the degree of unavoidable endangerment in attempting full compliance.

We do not consider the current remoteness of a pile from population centers sufficient by itself to justify relaxing the disposal standards. Even small numbers of people nearby require protection, and the population of an area could increase considerably over the one-thousand-year period during which the standards apply. Furthermore, radon released from tailings piles travels long distances.

We also do not consider cost a reason for noncompliance with the standards unless the cost is very high or the benefit very small. But it may not make sense to spend a great deal of money, for example, to clean up an infrequently occupied building where the standards are only slightly exceeded.

To allow PL 95-604 to be implemented reasonably in all of the varied curcumstances, we are proposing criteria which the implementers may use to determine whether particular circumstances are exceptional. In such exceptional cases, DOE may select and perform remedial actions which come as close to meeting the standards as is reasonable. In selecting such remedial actions, DOE shall ask any property owners and occupants for their comments; the concurrence of NRC shall be required, and DOE shall inform EPA.

9.3 Effects of Implementing the Standards

9.3.1 Health

The proposed standards reduce average radon emissions of the tailings piles by more than 99% for one thousand years. Extrapolating the current rate of lung cancer deaths over that period, we estimate applying the standards will prevent about 2,000 premature lung cancer deaths.

Some people now living very near tailings piles could bear a risk of premature death due to lung cancer of several chances in 100. Under the disposal standards, people living in comparable locations during the next thousand years will bear a risk from the pile of about 1 chance in 10,000.

After remedial actions are completed on buildings eligible under PL 95-604, their occupants will be subject to radon decay product concentrations of less than 0.015 WL (including background), and gamma radiation exposure rates lower than 0.02 mR/hr. Their estimated total risk of fatal cancer due to residual tailings following remedial action will average less than about 1%. This is within a normal range of fluctuation for risk from indoor radon decay products in the absence of tailings.

After remedial actions on eligible open land, residual contaminated materials will have less than five times the radon release of average soils. It could cause a gamma radiation dose of less than 80 millirad per year to a person who spends 24 hours a day outdoors on the site. These levels of radon emission and gamma radiation are within normal variations in undisturbed land areas. We believe that the actual radon and gamma ray levels after cleanup will usually be much less than the maximum permitted by these standards.

9.3.2 Environmental

Since the proposed standards call for effective control for at least one thousand years, dispersal by floods, erosion, or mass movement should not reasonably be expected to occur during that period. Releases of radon gas to the air from the site will be slightly above average, but within a normal range. High-quality ground water will be protected for a wide range of uses, including drinking; surface waters and lower-quality ground water will not be degraded by the tailings.

Contaminated open land will be subjected to scraping and digging by the cleanup operations. Generally these activities will occur immediately adjacent to the piles, but off-site areas where tailings have been deliberately used also will be affected. Disposal operations may require large quantities of clay and soil for covering the tailings, depending on the disposal method. The environmental effects of obtaining these materials will vary with the site. The general ecological effects of land cleanup and restoration operations are examined in detail in an EPA report (EP 78b).

9.3.3 Economic

Estimating the total cost of disposing of all the tailings piles eligible under PL 95-604 is difficult, primarily because methods will be chosen specifically for each site. We estimate the cost (in 1978 dollars) of covering an average pile to meet the proposed radon emission standard as $1 million to $6 million if the existing site is suitable, or $6 million to $13 million if the pile must be moved. The total disposal cost for all sites would then be $21 million to $273 million. Deep burial and chemical treatments could be considerably more expensive.

Cleanup costs for open land and buildings have been estimated using interim cleanup criteria as about $10 million (see Section 7.4). Even allowing for increased costs under the proposed standards, disposal is still by far the largest cost component of the remedial action program.

Although difficult to estimate, the total cost of the entire program probably will be $200 million to $300 million. The Federal government will assume a 90% share, and any State government in which an inactive processing site is located will pay 10%. We expect the expenditures will be spread over the seven-year authorization of the program. Most of these expenditures will occur in the regions where the tailings are located. Their significance depends on the amount expended, the size of the local economy, and the availability of necessary equipment and labor.

Contaminated land and buildings might be made available for use as a result of the cleanup program. On the other hand, moving tailings to a new location removes the new disposal site from other potential uses.

In summary, the program could result in net economic benefits of decreased unemployment and increased business activity for the regions where the piles are located. We expect little or no perceptible national economic impact because the total seven-year expenditures will be small compared to the annual Federal budget (less than 0.06% of 1978 budget), the annual Gross National Product (less than 0.01% of 1978 GNP), and the construction industry (less than 0.5% of 1978 billings).

9.4 The Proposed Standards

The proposed standards are presented in Appendix D.

References for Chapter 9

(EP 78a) "Response to Comments: Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment," EPA Technical Report 520/4-78-010.

(EP 78b) "The Ecological Impact of Land Restoration and Cleanup," August 1978, EPA Technical Report 520/3-78-006.

APPENDIX B

Development of Cost Estimates

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Development of Cost Estimates

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APPENDIX B

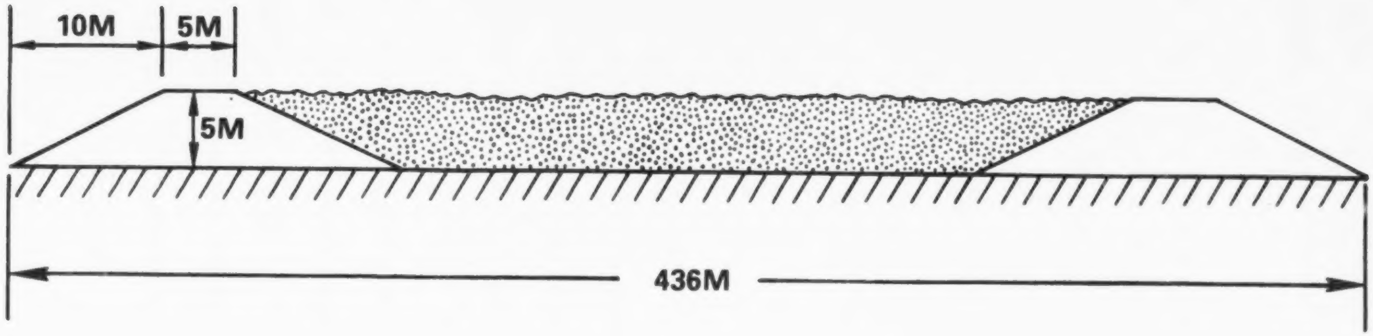
Development of Cost Estimates

B.1 The Average Inactive Uranium Mill Tailings Pile

To develop cost estimates of the various uranium mill tailings disposal methods, we employed an "average" inactive uranium mill tailings pile, with dimensions based upon the average dimensions found at the 21 inactive uranium mill tailings sites. The tailings area, volume, and weight dimensions have been computed from the information found in the Ford, Bacon and Davis, Utah, Inc, engineering reports on the inactive uranium mill tailings sites (FB 76-78).

The "average" pile has the configuration of a truncated regular pyramid with a lower base of 436m on a side, including embankments. Figure B-1 gives a cross section of the uranium mill tailings impoundment area. The mill tailings pile covers a surface area of a little more than 19 hectares (190,000m2, or 47 acres). The embankments contain 784,000m3 (1,026,000 yd3) of uranium mill tailings, weighing 1,325,000 short tons. The tailings are assumed to be 5.0m deep within the embankments. We further assumed that when the uranium milling operations ceased, the tailings pile was left flat on top but uncovered, and there is evidence of both wind and water erosion. Tests indicate that tailings have migrated as far as 1,000m from the "average" tailings pile.

FIGURE B - 1


10M
5M
5M
436M

CROSS-SECTION OF THE "AVERAGE" INACTIVE URANIUM MILL TAILINGS FILE

B.2 Development of Unit Cost Computations

The unit costs used for estimating the costs of the disposal options are presented in Table B-1. They are average costs and represent the expected monetary values that will be encountered while completing individual tasks, or purchasing specific items necessary for the various uranium mill tailings disposal methods considered in this report. The unit costs are in 1978 dollars and reflect the economic conditions of that year.

The procedures used to derive the unit costs are as follows:

a. Any costs not already in 1978 dollars are adjusted to reflect 1978 values using an appropriate price index (usually the U.S. Department of Commerce Composite Construction Cost Index published in the Survey of Current Business).

b. When only one source for the cost of an item is available, that value is used.

c. When more than one cost estimate is available, the average of these values is used.

B.2.1 Earth Work

The sources for computing the costs for various types of earth work are Dodge (DO 78), Means (ME 77), and the NRC-DGEIS (NR 79).

TABLE B-1

Unit Costs

Task	Cost (1978 dollars)
1. Earth work	
a. Below-grade excavation in normal soil	$1.63/m3
Below-grade excavation in shale	$3.10/m3
b. Dragline excavation and loading	$1.53/m3
c. Excavate, load, and haul	$1.13/m3
d. Spread and compact	$0.38/m3
e. Haul, dump, spread, and compact	$1.33/m3
2. Caps and Liners	
a. Clay (when available)	$2.07/m3
b. Clay (purchase required)	$5.00/m3
c. Synthetic	$4.41/m2
d. Asphalt emulsion (1/2" thick)	$1.76/m2
3. Stabilization	
a. Vegatation (when soil available)	$0.75/m2
b. Vegatation (when purchase required)	$2.51/m2
c. Riprap (.5m thick)	$12.90/m2
d. Gravel (.5m thick)	$2.57/m2
e. Chemical	$0.74/m2
4. Fencing	
a. Chain-link fence 5 to 6 feet high	$29.69/m
b. Security fence (prison grade)	$84.51/m
5. Irrigation	
a. Equipment (excluding pumps)	$1,070/hectare
b. Annual operating costs	$ 273/hectare
c. Submersible pump	$1,000 each

TABLE B-1 (continued)

Unit Costs

Task	Cost (1978 dollars)
6. Matrix Fixation	
a. Cement with thermal evaporator	
Capital costs	$4.75 million
Annual operating costs	$6.57 million
b. Cement with filter bed	
Capital costs	$6.55 million
Annual operating costs	$2.14 million
c. Asphalt with thermal evaporator	
Capital costs	$7.90 million
Annual operating costs	$8.51 million
d. Asphalt with filter bed	
Capital costs	$9.70 million
Annual operating costs	$4.07 million
7. Tailings Transportation	
a. Truck	$0.10/ton-mile
b. Rail	$0.08/ton-mile
c. Pipeline (7" diameter)	
Capital equipment and right-of-way	$63,840/mile
Operating costs	$0.048/ton-mile
8. Discount rate (real rate of return)	7%
9. Future Costs	
a. Vegetation stabilization	
Annual operating cost	$3,900/hectare
Irrigation equipment	$400/hectare
Submersible pump	$2,500 each
b. Chemical stabilization	$23,800/hectare
c. 5-6 foot chain-link fence	$4.27/m
d. Security fence (prison grade)	$12.17/m
10. Land Costs (farmland)	$781/hectare

There are two types of below-grade excavation, depending on the consistency of the material being excavated: normal or shale. Though classified as one category, normal below-grade excavation is not homogeneous; it includes digging in soft soil as well as in various forms of clay. Similarly, the costs of excavating in such a variety of soil types can vary significantly. As a result, the expected cost for normal below-grade excavation is $1.63/m3, but may actually range anywhere between $0.56/m3 and $5.98/m3. The average cost for below-grade excavation of shale, on the other hand, rises to $3.10/m3, and may range between $2.56/m3 and $3.81/m3.

According to Ford, Bacon and Davis, Utah, Inc. (FB 76-78), a dragline method of tailings excavation is required to remove the uranium mill tailings from their present site. This method of tailings excavation is assumed throughout this report. Estimates of dragline excavation and loading establish the cost for removing the uranium mill tailings at $1.53/m3.

Excavating, loading, and hauling surface soil up to one mile is expected to cost $1.13/m3, but may be as low as $0.92/m3 or as high as $1.58/m3. Spreading and compacting materials (such as mill tailings, top soil, clay, etc.) will average $0.38/m3, but may range between $0.22/m3 and $0.75/m3. Finally, hauling up to one mile, dumping, spreading, and compacting is expected to cost $1.33/m3, and is considered a single task.

B.2.2 Caps and Liners

The sources for unit cost estimates of caps and liners are Dames and Moore (DA 77), the NRC-DGEIS (NR 79), and Smith and Lambert (SM 78).

There are basically three types of caps and liners: clay, synthetic, and asphaltic emulsion. The major purpose of a cap is to reduce radon emissions from the mill tailings into the surface environment. A cap also affords some hydrologic control by reducing seepage of surface water into the tailings. Liners, on the other hand, are used chiefly to provide hydrologic control beneath the pile. That is, a liner will reduce moisture seepage from the mill tailings into the ground water or ground water infiltration into the tailings.

Assuming a nearby source of suitable clay (that is, with a large proportion of montmorillonite) is available at no cost, a clay cap or liner can be expected to cost \$2.07/m3 to install, but may actually range between \$1.14/m3 and \$2.93/m3. If a suitable type of clay must be purchased, an additional \$2.93/m3 should be added to the cost of installing a clay cap or liner.

Many types of synthetic materials are available which could be used as a cap or liner for uranium mill tailings (e.g., polyester-reinforced Hypalon or Polyvinylchloride). Because these types of caps and liner require a carefully prepared installation, they can be quite expensive.

On average, \$4.41/m2 is the expected cost of installing a synthetic cap or liner, but the cost may range between \$2.00/m2 and \$11.89/m2.

The least expensive method of providing a cap or liner for uranium mill tailings appears to be an asphaltic emulsion. Smith and Lambert (SM 78) estimate that the cost of applying a 0.5-inch-thick layer of asphaltic emulsion costs \$7,140 an acre or \$1.76/m2.

B.2.3 Stabilization

All methods of stabilizing uranium mill tailings disposal sites have a common purpose; that is, to protect against wind and water erosion. This reduces the quantity of uranium mill tailings that migrate from the disposal site. Four methods of stabilization are considered in this report: vegetation, riprap, gravel, and chemical.

a. Vegetation as a stabilizer consists of plants to hold the surface in place. The proper installation of vegetation requires approximately eight inches of suitable surface soil to insure plant propagation. Besides seeding, fertilizer, lime, and soil binders are also necessary to aid plant growth until a ground cover is established. If it is assumed that suitable top soil is available locally, the cost of providing a vegetation cover will cost \$0.75/m2, but may range between \$0.38/m2 and \$1.12/m2. If top soil and loam must be purchased, then the cost of vegetation becomes significantly more expensive (\$2.51/m2 on average, ranging between \$1.48/m2 and \$3.93/m2). These cost estimates do not include the irrigation costs for areas without adequate precipitation. The capital and operating expenditures associated with irrigation are discussed later.

b. Riprap consists of large stone or concrete chips (1/4 yd3 to 3/8 yd3 in size) in a layer approximately 0.5m thick as a cover on the uranium mill tailings disposal site. Riprap is either placed loose or enclosed in galvanized steel mesh boxes called gabions. Riprap has an average installation cost of $\$12.90/m^2$. If placed loose, riprap can cost as little as $\$4.78/m^2$. But if the riprap must be enclosed in gabions, the cost of a riprap cover may be as high as $\$25.79/m^2$.

c. Like riprap, gravel provides wind and water erosion protection for the uranium mill tailings disposal site, and an 0.5m-thick cover of gravel is assumed to be required for adequate wind and water erosion protection. Installing a 0.5m-thick gravel cover costs $\$2.57/m^2$, on average, but ranges between $\$2.49/m^2$ and $\$2.73/m^2$.

d. Other types of covers, categorized here as chemical stabilizers, include asphalt, asphaltic emulsion, road oil, and various other chemicals. Although the chemical stabilizers appear to be the least expensive method of stabilizing a uranium mill tailings disposal site (the average installation cost is $\$0.75/m^2$), the application cost ranges widely, between $\$0.05/m^2$ and $\$9.69/m^2$. Further, their long-term stability is untested. Some methods require replacement in less than a year while others may last 20 years or more. For cost estimates, we assumed that a chemical stabilizer will need replacement every four years.

B.2.4 Fencing

Sources for unit costs of fencing are Dodge (DO 78), Means (ME 77), the NRC-DGEIS (NR 79), and Smith and Lambert (SM 78).

Isolation of the uranium mill tailings disposal site from intrusion can be accomplished by a fence. We considered two types of fences in this report. A chain-link fence five to six feet high, with or without several strands of barbed wire on top, costs an average of $29.69/m to install, but may range between $21.33/m and $49.21/m. If more security is required, a prison-grade security fence 12 to 16 feet high will cost $84.51/m to install, but may be as low as $73.49/m or as high as $95.54/m. These costs include installation, corner posts, and a gate. The effective life of these fences is assumed to be one hundred years, with proper maintenance. Annual maintenance for the fences is expected to be cost 1% of the original expenditure for the fences.

B.2.5 Irrigation

The capital and annual operating expenditures for irrigation used in this report have been taken from the NRC-DGEIS (NR 79). All costs are stated on a per hectare basis, except for submersible pumps. Annual operating expenditures for running and maintaining irrigation equipment are expected to be $273 per year per hectare. This value includes fertilizer, power, operating labor, maintenance on the irrigation equipment, and ground water analyses. Installation of the irrigation equipment, including pumps and miscellaneous valves and nozzles, will cost $1,070 per hectare. It is expected that this equipment will need replacement an average of every 20 years. In addition, one submersible pump, at a cost of $1,000 is required for every 20 hectares irrigated. Replacement of the submersible pumps can be expected every five years.

B.2.6 Matrix Fixation

Uranium mill tailings could be incorporated into a concrete or asphalt mixture, reducing the leachability of the tailings into the hydrologic system. A detailed discussion of the methods and requirements for fixing uranium mill tailings in a concrete or asphalt matrix can be found in the NRC-DGEIS (NR 79).

Detailed breakdowns of the estimated capital expenditures and annual operation costs for the various methods of matrix fixation are given in Tables B-2 and B-3. These tables have been taken directly from the NRC-DGEIS (NR 79), Tables 11.9 and 11.10, respectively.

From a cost standpoint, significant savings can be realized in initial capital costs and in annual operating expenditures if a cement rather than asphalt matrix is used. In addition, the method of drying the tailings before incorporation into either a cement or asphalt matrix has significant cost implications. For both concrete and asphalt

TABLE B-2

Estimated Capital Costs for Matrix Fixation[a]

(thousands of 1978 dollars)

Equipment	Thermal Evaporator		Filter Bed	
	Cement	Asphalt	Cement	Asphalt
Sand washing and drying	$ 230	$ 230	$ 230	$ 230
Lime neutralization	670	670	670	670
Slimes filtration (vacuum disc filter)	1,150	1,150	---	---
Tailings dewatering bed	---	---	2,120	2,120
Evaporators	1,470	1,470	---	---
Evaporation pond	---	---	2,300	2,300
Asphalt fixation	---	4,400	---	4,400
Cement fixation	1,210	---	1,210	---
TOTAL	$4,750	$7,900	$6,550	$9,700

(a)NRC-DGEIS (NR 79), Table 11.9.

TABLE B-3

Annual Operating Costs for Matrix Fixation[(a)]

(thousands of 1978 dollars)

Costs	Thermal Evaporator Cement	Thermal Evaporator Asphalt	Filter Bed Cement	Filter Bed Asphalt
Salaries	$ 170	$ 170	$ 85	$ 85
Maintenance	110	170	50	100
Power	75	75	35	35
Fuel	4,250	4,740	---	490
Asphalt	---	3,360	---	3,360
Cement	1,970	---	1,970	---
TOTAL (annual)	$6,575	$8,515	$2,140	$4,070

(a)NRC-DGEIS (NR 79), Table 11.10.

fixation, initial capital costs are somewhat less expensive for mechanically drying the tailings with a thermal evaporator than with a "dewatering filter bed" (a sand filter). Significant savings in annual operating expenditures can be gained, however, by using the "dewatering filter bed" rather than the thermal evaporator. That is, annual operating costs are at least a factor of two less than those for a thermal evaporator for both cement and asphalt matrix fixation.

B.2.7 Tailings Transportation

We considered three methods of hauling uranium mill tailings: truck, rail, and slurry pipeline. According to Ford, Bacon and Davis, Utah, Inc. (FB 76-78), contract haulers can transport mill tailings at a cost of $0.10/ton-mile. For longer distances of 50 miles or more, rail transport, at $0.08/ton-mile, offers some cost advantages over trucking. Unless the tailings pile is located at a rail head, however, the tailings will have to be hauled to the rail line by truck.

Transporting uranium mill tailings by pipeline offers greatly reduced operating expenditures as compared to either truck or rail, but requires heavy initial capital and right-of-way costs. According to Dames and Moore (DA 77), a pipeline 7" in diameter costs $63,840/mile to construct and to reserve the right-of-way. Transporting mill tailings via such a pipeline is estimated to cost $0.048/ton-mile.

B.2.8 Discount Rate

The discount rate is assumed to be 7%. This is the estimated average real rate of return considering all elements of society (NR 76). The real rate of return is the current rate of return minus the inflation rate. The discount rate is used for computing the present discounted value of future costs (to maintain and replace fences in the future, for example).

B.2.9 Present Worth of Future Costs

Several control methods may require perpetual care or periodic replacement in order to maintain the intended level of effectiveness. For example, we assumed that chemical stabilization needs replacement every four years. Fences are assumed to require annual maintenance, and replacement every hundred years. Finally, natural precipitation may need to be supplemented with irrigation to maintain a proper vegetation cover for surface stabilization. The irrigation system is assumed to require annual maintenance, and periodic replacement.

The present worth of all future costs are included in the cost breakdown shown in the tables where appropriate. The formula used for present worth calculations is:

$$\frac{C}{(1+i)^n - 1},$$

where: PW = present worth,
C = replacement cost of the item considered, or its periodic maintenance cost,
n = the useful life of the item, or the periodic maintenance period,
i = the annual discount rate.

This formula assumes that maintenance and replacement continues indefinitely. The annual discount rate used in all calculations is 7%.

B.2.10 Land Costs

Smith and Lambert (SM 78) estimate that farmland costs an average of $781 per hectare, and may range between $160 and $5,189 per hectare.

B.3 Cost Estimates For Disposal Options

Using the estimated unit costs (from Table B-1) and assuming the dimensions of the average inactive uranium mill tailings pile, we have estimated costs for the tasks necessary to complete various disposal options. When considered as various combinations of the tasks, the estimated costs offer numerous control options. In actual practice, the choice of a specific disposal option and actual control cost will depend on such site-specific parameters as the radon emission rate, size, and condition of the specific mill tailings pile.

B.3.1 Option 1 - No Radon Control

This option may be implemented either by constructing a fence around the existing disposal site (thereby restricting access) or by stabilizing the existing mill tailings pile to reduce future wind and water erosion.

B.3.1.1 Option 1a - Fencing

In this disposal option, the uranium mill tailings pile is left at its existing surface location and a fence is erected around the site. No control of radon-222 releases, particulate releases, or ground water impacts is provided, although fencing provides some control of direct gamma radiation by preventing people from living near the tailings pile. It is assumed that wind erosion can cause particulates to migrate as far as 1000m from the pile. Therefore, it is assumed that a 1000m exclusionary zone is required on all sides of the tailings pile.

The cost of a fence can be expected to range between $290,000 for a chain-link fence five to six feet high and $820,000 for a security fence of prison grade. The present worth of annual maintenance and replacement every hundred years is estimated to be $40,000 for a chain link fence and $120,000 for a security fence.

In either case, the fence encloses 593.4 hectares of land. The tailings pile is assumed to be on a 49-hectare site that is already publicly owned. It is assumed that the remaining 544.4 hectares must be purchased, at a cost of $430,000. The 49 hectares already under public ownership represent a cost to society, since they are unavailable for alternative uses. The best alternative use is assumed to be agricultural. The "opportunity cost," or market value, of the land is an estimated $40,000. In total, the cost of the "no control" option is $790,000 if a chain-link fence five to six feet high is used, and $2.4 million if a security fence is employed.

B.3.1.2 Option 1b - Stabilization With No Radon Control

The mill tailings pile is left in place in this disposal option but stabilized to prevent wind and water erosion. Several of the existing inactive tailings piles have already been stabilized with about six inches of soil cover, vegetation, gravel, or riprap. The equivalent of 0.5m of riprap cover is required to ensure longevity. A 15cm to 0.5m dike cover would meet short-term requirements, but would be subject to both wind and water erosion and thus subsequent degradation. Riprap cover has been utilized at one pile and experience with stabilization of large tailings piles is quite limited. This level of control might be accomplished through the use of chemical sprays, which either form a surface crust or bind the surface tailings into a crust. Experience with such methods, however, indicates that the resulting crusts are not resistant to environmental degradation (Tuba City and Salt Lake City (FB 76)). The degradation results from intrusion by man and animals, ultraviolet radiation, and various climatological effects. Chemical sprays and binders appear to require a protective layer of dirt or riprap to assure even a relatively short lifetime of 10 years. Thus, they have a limited applicability for this level of control.

The sides of the tailings pile must be shaped to a slope ratio of 8:1 to minimize future erosion and a 20m exclusionary zone should be provided around the pile. Besides a chain-link fence and a security fence, several stabilization methods are considered here. Vegetation could be employed, but may require the purchase of suitable top soil or an irrigation system. Potentially, riprap and gravel could provide long-term wind and water erosion protection. Finally, chemical stabilizers provide erosion protection but are expected to need replacement every four years.

Table B-4 presents the cost and dimension estimates for the alternative methods that will control particulates at the model uranium mill tailings pile.

At a minimum, the total cost of providing wind and water erosion protection for the model mill tailings pile will be $500,000. This includes: enough earthwork to change the embankment slopes from 2:1 to 8:1, stabilization by vegetation that requires neither soil purchase or irrigation, and a chain-link fence five to six feet high. On the other hand, the level of control could cost as much as $3.6 million if the model pile must be stabilized by riprap and isolated by a security fence.

TABLE B-4

Costs and Dimensions of Particulate Control

Volume of earth work (m3)	135,000
Area of cover (m2)	247,000
Length of fence (m)	2,140
Area within fence (m2)	287,000

------------------Costs (in thousands of 1978 dollars)------------------	
Earth work	200
Stabilization	
Veg: With no need to purchase soil	180
With purchase of soil	620
Irrigation (labor & equip.)	40
Riprap	3,180
Gravel	630
Chemical	180
Fencing	
Chain-link, five to six feet high	60
Security (prison grade)	180
Future Costs	
Irrigation (labor & equip.)	110
Chemical stabilization	590
Chain-link fence	10
Security fence	30
Value of Land	20

B.3.2 Controlling Radon Emissions with an Overburden

As noted in the NRC-DGEIS (NR 79), radon emanation can be reduced by appropriately thick overburden. The overburden may be a layer of soil or a combination of soil and a cap consisting of asphalt, clay, or synthetic material. For Option 2 (Existing Surface Site, Covered to Control Radon) and Option 3 (New Site, Below Grade, with Liner if Needed), seven types of overburden are considered for dimension and cost estimation. The required thickness of overburden needed to provide the five selected radon attenuation levels for each type of overburden are presented in Table B-5.

B.3.3. Option 2 - Existing Surface Site, Covered to Control Radon Emissions

This disposal option consits of covering the tailings pile at the existing surface site for control of radon-222 releases. In addition, this control option reduces wind and water erosion of the mill tailings, attenuates gamma radiation, and provides some control of ground water contamination. Basically, this option requires three steps: covering the mill tailings, stabilizing the pile against wind and water erosion, and fencing the disposal area to prevent intrusion. There are several ways to accomplish each steps. This leads to numerous possible combinations of methods to implement this disposal option. The steps and their alternative methods are given in Table B-6.

TABLE B-5

Thickness (meters) of Cover Required to Reduce Radon to Control Level

	Radon Control Level (pCi/m^2/sec)				
	100	10	5	2	0.5
Soil(a)	1.1	2.9	3.4	4.1	5.1
Soil + 0.6 m Clay(b)	0.3	0.9	1.4	2.1	3.2
Soil + 1.0 m Clay(c)	0.3	0.7	0.8	1.0	1.9
Soil + Asphalt(d)	--	--	--	--	0.5
Soil + Synthetic(d)	--	--	--	--	0.5

(a)Soil with average radon-attenuating properties.

(b)Thickness includes both clay and soil. If thickness is 0.6m or less then includes clay only.

(c)Thickness includes both clay and soil. If thickness is 1.0m or less then includes clay only.

(d)Asphalt and synthetic caps are assumed to reduce radon to at least 1.0 pCi/m2 sec. Thickness only includes soil. The dashes (--) mean no soil is required.

Source: NRC-DGEIS, Table K-6.1, p.K-27. (Ref. NR 79)

TABLE B-6

Control Methods for Disposal Option 2
(Existing Surface Site, Covered to Control Radon)

1. Cover

   a. Soil (normal radon-attenuation properties)
   b. Soil + 0.6m clay (no clay purchase required)
   c. Soil + 0.6m clay (clay purchase required)
   d. Soil + 1.0m clay (no clay purchase required)
   e. Soil + 1.0m clay (clay purchase required)
   f. Soil + asphalt
   g. Soil + synthetic

2. Stabilization

   a. Vegetation (no soil or loam purchase required)
   b. Vegetation (soil or loam purchase required)
   c. Irrigation required (a or b)
   d. Irrigation not required (a or b)
   e. Riprap
   f. Gravel
   g. Chemical

3. Fence

   a. Chain-link fence five to six feet high
   b. Security fence (prison grade)

B.3.3.1 Dimensions

All dimensions assume that the existing uranium mill tailings piles and the resultant disposal mounds are in the shape of truncated regular pyramids. By assumption, the sides of the final disposal mound have a slope ratio of 8:1 in order to resist future wind and water erosion. Also, an exclusionary zone of 20m from the base of the final disposal mound is assumed. Finally, the dimensions and conditions of the average inactive uranium mill tailings pile are those described in Section B.1.

B.3.3.2 Cost Estimates

Cost estimates based on the dimensions of the average inactive uranium mill tailings pile are presented for each of five selected radon attenuation levels in Tables B-7 through B-11. Cost estimates for various tasks necessary to implement Option 2 are found in these tables. Note that the total cost of implementing Option 2 will vary with such things as the desired radon attenuation level, the selected type of overburden, the method of stabilization, and the fencing.

Several points concerning the derivation of the cost estimates need some explanation:

1. The volume of earth work, specific to a type of cover, does not include the volume of the cap. With clay caps, for example, the volume of the cap is not included in the volume of the earth work.

TABLE B-7

Costs and Dimensions for Disposal

Option 2 with Control of Radon to 100 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	1.1	.3	.3	-
Volume of cover (m3)	415,000	209,000	209,000	-
Area of cover (m2)	264,000	251,000	251,000	-
Length of fence (m)	2,210	2,160	2,160	-
Area within fence (m2)	306,000	292,000	292,000	-
------------------Costs (in thousands of 1978 dollars)------------------				
Earth work	$ 630	$ 240	$ 240	-
Cap				
Clay				
With clay available	-	110	110	-
With clay purchase	-	260	260	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-
Stabilization				
Veg: No need to purchase soil	200	190	190	-
With purchase of soil	660	630	630	-
Irrigation (labor & equip.)	40	40	40	-
Riprap	3,410	3,240	3,240	-
Gravel	680	650	650	-
Chemical	200	190	190	-
Fencing				
Chain link, five to six feet high	70	60	60	-
Security (prison grade)	190	180	180	-
Future Costs				
Irrigation (labor & equip.)	120	110	110	-
Chemical stabilization	630	600	600	-
Chain-link fence	10	10	10	-
Security fence	30	30	30	-
Value of land	20	20	20	-

TABLE B-8

Costs and Dimensions for Disposal Option 2 with Control of Radon to 10 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	2.9	.9	.7	-
Volume of cover (m3)	917,000	363,000	311,000	-
Aera of cover (m2)	295,000	261,000	258,000	-
Length of fence (m)	2,330	2,200	2,190	-
Area within fence (m2)	339,000	303,000	299,000	-

------------------Costs (in thousands of 1978 dollars)---------------

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Earth Work	$1,380	$ 390	$ 290	-
Cap				
Clay				
With clay available	-	210	250	-
With purchase of clay	-	520	610	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-
Stabilization				
Veg: No need to purchase soil	220	200	190	-
With purchase of soil	740	660	650	-
Irrigation (labor & equip.)	40	40	40	-
Riprap	3,810	3,370	3,330	-
Gravel	760	670	660	-
Chemical	220	190	190	-
Fencing				
Chain link	70	70	70	-
Security (prison grade)	200	190	190	-
Future Costs				
Irrigation (labor & equip.)	130	120	120	-
Chemical stabilization	700	620	610	-
Chain-link fence	10	10	10	-
Security fence	30	30	30	-
Value of Land	30	20	20	-

TABLE B-9

Costs and Dimensions for Disposal Option 2 with Control of Radon to 5 $pCi/m^2/sec$

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	3.4	1.4	.8	-
Volume of cover (m3)	1,066,000	495,000	337,000	-
Area of cover (m2)	304,000	269,000	260,000	-
Length of fence (m)	2,360	2,230	2,200	-
Area within fence (m2)	349,000	312,000	301,000	-

------------------Cost (in thousands of 1978 dollars)---------------------

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Earth Work	$1,610	$ 590	$ 300	-
Cap				
Clay				
With clay available	-	210	290	-
With clay purchase	-	520	690	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-
Stabilization				
Veg: No need to purchase soil	230	200	190	-
With purchase of soil	760	680	650	-
Irrigation (labor & equip.)	40	40	40	-
Riprap	3,920	3,480	3,350	-
Gravel	780	690	670	-
Chemical	220	200	190	-
Fencing				
Chain link	70	70	70	-
Security (prison grade)	200	190	190	-
Future Costs				
Irrigation (labor & equip.)	140	120	120	-
Chemical stablization	720	640	620	-
Chain-link fence	10	10	10	-
Security fence	30	30	30	-
Value of Land	30	20	20	-

TABLE B-10

Costs and Dimensions for Disposal Option 2 with Control of Radon to 2 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	4.1	2.1	1.0	-
Volume of cover (m3)	1,283,000	687,000	389.000	-
Area of cover (m2)	317,000	281,000	263,000	-
Length of fence (m)	2,410	2,280	2,210	-
Area within fence (m2)	362,000	324,000	305,000	-
--------------------Costs (in thousands of 1978 dollars)----------------				
Earth Work	$1,940	$ 880	$ 330	-
Cap				
Clay				
With clay available	-	210	360	-
With clay purchase	-	520	870	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-
Stabilization				
Veg: No need to purchase soil	240	210	200	-
With purchase of soil	790	710	660	-
Irrigation (labor & equip.)	40	40	40	-
Riprap	4,080	3,630	3,390	-
Gravel	810	720	680	-
Chemical	230	210	190	-
Fencing				
Chain link	70	70	70	-
Security (prison grade)	200	190	190	-
Future Costs				
Irrigation (labor & equip.)	140	130	120	-
Chemical stabilization	750	670	630	-
Chain-link fence	10	10	10	-
Security fence	30	30	30	-
Value of Land	30	20	20	-

TABLE B-11

Costs and Dimensions for Disposal Option 2 with Control of Radon to 0.5 $pCi/m^2/sec$

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	5.1	3.2	1.9	.5
Volume of cover (m3)	1,607,000	1,006,000	631,000	260,000
Area of cover (m2)	335,000	300,000	278,000	255,000
Length of fence (m)	2,470	2,350	2,270	2,180
Area within fence (m2)	381,000	345,000	321,000	296,000

----------------------Costs (in thousands of 1978 dollars)---------------

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Earth Work	\$2,430	\$1,360	\$ 690	\$ 390
Cap				
Clay				
With clay available	-	210	360	-
With clay purchase	-	520	870	-
Other				
Asphalt	-	-	-	300
Synthetic	-	-	-	760
Stabilization				
Veg: No need to purchase soil	250	230	210	190
With purchase of soil	840	750	700	640
Irrigation (labor & equip.)	50	40	40	40
Riprap	4,320	3,880	3,590	3,290
Gravel	860	770	710	650
Chemical	250	220	200	190
Fencing				
Chain link	70	70	70	60
Security (prison grade)	210	200	190	180
Future Costs				
Irrigation (labor & equip.)	150	130	120	110
Chemical stabilization	800	720	660	610
Chain-link fence	10	10	10	10
Security fence	30	30	30	30
Value of Land	30	30	30	20

2. Earth work includes excavating, loading, hauling up to one mile, spreading, and compacting surface soil.

3. Caps are assumed to cover both the tailings and the crest of the impoundment dikes.

4. Asphalt and synthetic caps are expected to reduce radon releases to 1.0 pCi/m2/sec without additional soil cover. As a result, cost estimates for covers involving asphalt or synthetic caps have been computed only for radon control levels of 1.0 pCi/m2/sec and below.

5. Several control methods in Table B-6 require periodic maintenance and replacement of equipment (e.g., irrigation equipment, chemical stabilizers, and fences). The discounted present value of these future costs have been computed in each case.

6. After control measures are completed, the use of land within the fences will presumably be restricted. Alternative uses, such as agricultural, therefore will be permanently denied. This opportunity cost should be considered in the decision-making process along with the other costs. For this purpose, the restricted land is assumed to have agricultural uses, and the opportunity cost is equal to the market value of the property.

B.3.3.3 Use of Tables B-7 Through B-11

Since Tables B-7 through B-11 present only the costs of accomplishing particular tasks that might be employed in a control option, it is important for the reader to understand the proper use of these tables for deriving the total cost for a desired control option.

After selecting the desired radon attenuation level and type of overburden (i.e., reading down one column of the selected table) one can calculate a total cost for the selected control option.(1) The total cost is then equal to the sum of the cost of the required overburden (earth work plus cap costs), the cost of the specific method of stabilization (plus the cost of irrigation if required), the cost of the desired fence, the necessary future costs, and the market value of the land. For example, the total cost of attenuating to a radon flux equal to 5 pCi/m2/sec (refer to Table B-9) is $1.2 million, if soil plus a 1.0m clay cap is used as an overburden (assuming a suitable clay is locally available at no cost). We assumed that the site is stabilized with vegetation requiring both the purchase of top soil and irrigation equipment, and that a chain-link fence five to six feet high is required.

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(1)The column labeled "Soil + Other" in Tables B-7 through B-11 actually represents two separate types of overburden; the combinations of soil, and asphalt or synthetic caps. In either case, only the cost of the asphalt or synthetic caps differ.

B.3.4 Option 3 - New Site, Below Grade, with Liner if Needed

The objective of Option 3 is not only to reduce radon emission and gamma radiation, but also to provide greater hydrologic control than Option 2 would afford.

B.3.4.1 Requirements

In addition to the three steps necessary to implement Option 2, this option requires excavating a special pit, installing a liner (if necessary), and transporting the tailings to the pit site. The need for a liner depends on the subsoil characteristics at the new site. If the subsoil is relatively impervious to moisture seepage (e.g., clay with a high montmorillonite content, or impervious shale), then a special liner may not be required. Also, a pit above the water table may obviate the need for a liner. For this option, transporting the tailings includes excavating the tailings from their present site, hauling them to the new site, and depositing the mill tailings in the pit.

Like Option 2, there are several ways of accomplishing each step of this option. Table B-12 presents each step and alternatives. Considering each possible combination presented in Table B-12 leads to numerous methods of implementing this disposal option.

TABLE B-12

Control Methods for Disposal Option 3
(New Site, Below Grade, with Liner if Needed)

1. Tailings Transportation
    a. Truck
    b. Truck and rail
    c. Pipeline

2. Below-Grade Excavation
    a. Normal
    b. Shale (ripping necessary)

3. Liner
    a. Clay (with clay available)
    b. Clay (clay purchase required)
    c. Asphalt
    d. Synthetic
    e. None

4. Cover
    a. Soil (normal radon-attenuation properties)
    b. Soil + 0.6m clay (with clay available)
    c. Soil + 0.6m clay (clay purchase required)
    d. Soil + 1.0m clay (with clay available)
    e. Soil + 1.0m clay (clay purchase required)
    f. Soil + asphalt
    g. Soil + synthetic

5. Stabilization
    a. Vegetation (no soil or loam purchase required)
    b. Vegetation (soil or loam purchase required)
    c. Irrigation required (a or b)
    d. Irrigation not required (a or b)
    e Riprap
    f. Gravel
    g. Chemical

6. Fence
    a. Chain-link fence five to six feet high
    b. Security fence (prison grade)

B.3.4.2 Dimensions and Cost Estimates

For each of five selected radon attentuation levels, we calculated dimensions and costs for the various control methods for implementing Option 3 (Table B-12). The distance to the new disposal site and the geometric configuration of the pit are assumed constant in this analysis. Several of the dimensions (and, therefore, the costs) also remain constant regardless of the depth and type of overburden placed over the mill tailings, while other dimensions (and costs) vary. These constant costs are given in Table B-13.

As previously noted, there are 784,000m3 of uranium mill tailings (weighing 1,325,000 short tons) to be excavated by dragline and hauled to the pit site. The area to be stabilized is 176,000m2 (the pit, regardless of depth, is assumed to a square 420m on a side). Similarly, 1,840m of fencing will be required to enclose 212,000m2 of land (including both the pit and the exclusionary zone which is 20m on each side). The excavated pit is assumed to be in the shape of a truncated inverted regular pyramid whose sides are required to have a slope ratio of 3:1.

We assumed that the pit site is located 10 miles from the inactive mill tailings site. Rail heads are assumed to be situated one mile from both the inactive tailings site and the pit site. It is assumed that the land for the pit and its exclusion zone will be purchased at the market

TABLE B-13

Constant Costs for Below-Grade Disposal of Uranium Mill Tailings

	In thousands of 1978 dollars
Excavate, load, spread, and compact tailings	$1,500
Tailings Transportation	
Truck	1,300
Truck and rail	1,100
Pipline	1,280
Stabilization	
Veg: No soil purchase	130
With soil purchase	440
Irrigation (labor and equip.)	30
Riprap	2,280
Gravel	450
Chemical	130
Fencing	
Chain link	50
Security (prison grade)	160
Land Cost	20
Future costs	
Irrigation (labor and equip.)	100
Chemical stabilization	500
Chain-link fence	10
Security fence	20

value of farmland. For this disposal option "earth work" means below-grade excavation, hauling up to one mile, dumping, spreading, and compacting subsoil, and disposing of any excavated subsoil not used in the cover. The costs that vary by radon control level are given in Tables B-14 through B-18 for each selected level.

B.4 Other Disposal Methods

There are several high-cost alternatives to the disposal methods previously considered. These methods are discussed in the NRC-DGEIS (NR 79). Two of these methods are considered here: burial in a strip-mine or underground mine, and nitric acid leching for the removal of hazardous materials. Potentially, these alternatives offer considerable radon attenuation (below 0.5 pCi/m2/sec), but the long-term environmental impact of these methods has not been tested.

B.4.1 Extraction and Disposal of Hazardous Materials

Technology has not been developed for extracting radium or nonradiological toxic elements from the tailings, because until now there has been no need for this method

A nitric acid leaching plant could be set up to remove the radium and thorium in the tailings. Tailings from this process would still require some treatment, though the radioactivity level would be considerably lower. Some hazardous nonradiological elements would remain. Seepage from the new pile would contain nitrates instead of the sulfates found in

TABLE B-14

Variable Costs and Dimensions for Disposal

Option 3 with Control of Radon to 100 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	1.1	.3	.3	-
Vol. of pit				
With clay liner (m3)	1,145,000	1,014,000	1,014,000	-
No clay liner (m3)	975,000	837,000	837,000	-
Vol. of clay liner (m3)	170,000	177,000	177,000	-
Area for other liner (m2)	172,000	176,000	176,000	-
Vol. of clay cap (m3)	-	53,000	53,000	-
Area for other cap (m2)	-	-	-	-

------------------------Costs (in thousands of 1978 dollars)---------------

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Earth work				
No clay liner				
Normal digging	$2,890	$2,480	$2,480	-
Shale	4,320	3,710	3,710	-
Clay liner				
Normal digging	3,390	3,000	3,000	-
Shale	5,100	4,490	4,490	-
Liner				
Clay				
Clay available	350	370	370	-
With clay purchase	850	890	890	-
Other				
Asphalt	300	310	310	-
Synthetic	760	780	780	-
Cap				
Clay				
With clay available	-	110	110	-
With clay purchase	-	260	260	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-

TABLE B-15

Variable Costs and Dimensions for Disposal

Option 3 with Control of Radon to 10 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	2.9	.9	.7	-
Vol. of pit				
With clay liner (m3)	1,436,000	1,111,000	1,078,000	-
No clay liner (m3)	1,275,000	941,000	906,000	-
Vol. of clay liner (m3)	162,000	170,000	172,000	-
Area for other liner(m2)	163,000	173,000	174,000	-
Vol. of clay cap (m3)	-	104,000	122,000	-
Area for other cap (m2)	-	-	-	-
------------------------Costs (in thousands of 1978 dollars)------------				
Earth work				
No clay liner				
Normal digging	$3,770	$2,790	$2,680	-
Shale	5,650	4,170	4,020	-
Clay liner				
Normal digging	4,250	3,290	3,190	-
Shale	6,360	4,920	4,780	-
Liner				
Clay				
With clay available	330	350	360	-
With clay purchase	810	850	860	-
Other				
Asphalt	290	300	310	-
Synthetic	720	770	770	-
Cap				
Clay				
With clay available	-	220	250	-
With clay purchase	-	520	610	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-

TABLE B-16

Variable Costs and Dimensions for Disposal

Option 3 with Control of Radon to 5 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Othe
Depth of cover (m)	3.4	1.4	.8	-
Vol. of pit				
With clay liner (m3)	1,514,000	1,195,000	1,095,000	-
With no liner (m3)	1,355,000	1,026,000	924,000	-
Vol. of clay liner (m3)	158,000	168,000	172,000	-
Area for other liner (m2)	161,000	171,000	174,000	-
Vol. of clay cap (m3)	-	103,000	140,000	-
Area for other cap (m2)	-	-	-	-

------------------------Costs (in thousands of 1978 dollars)--------------

Earth work				
No clay liner				
Normal digging	$4,010	$3,040	$2,730	-
Shale	6,000	4,550	4,090	-
Clay liner				
Normal digging	4,480	3,540	3,240	-
Shale	6,710	5,290	4,850	-
Liner				
Clay				
With clay available	330	350	360	-
With clay purchase	790	840	860	-
Other				
Asphalt	280	300	310	-
Synthetic	710	750	770	-
Cap				
Clay				
With clay available	-	210	290	-
With clay purchase	-	510	700	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-

TABLE B-17

Variable Costs and Dimensions for Disposal

Option 3 with Control of Radon to 2 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	4.1	2.1	1.0	-
Vol. of pit				
With clay liner (m3)	1,621,000	1,308,000	1,128,000	-
No clay liner (m3)	1,468,000	1,144,000	958,000	-
Vol. of clay liner (m3)	155,000	165,000	170,000	-
Area for other liner (m2)	158,000	167,000	173,000	-
Vol. of clay cap (m3)	-	100,000	174,000	-
Area for other cap (m2)	-	-	-	-
------------------------Costs (in thousands of 1978 dollars)--------------				
Earth work				
No clay liner				
Normal digging	$4,340	$3,390	$2,840	-
Shale	6,490	5,070	4,240	-
Clay liner				
Normal digging	4,800	3,870	3,340	-
Shale	7,180	5,800	5,000	-
Liner				
Clay				
With clay available	320	340	350	-
With clay purchase	780	820	850	-
Other				
Asphalt	280	290	300	-
Synthetic	700	740	760	-
Cap				
Clay				
With clay available	-	210	360	-
With clay purchase	-	500	870	-
Other				
Asphalt	-	-	-	-
Synthetic	-	-	-	-

TABLE B-18

Variable Costs and Dimensions for Disposal

Option 3 with Control of Radon to 0.5 pCi/m^2/sec

	Soil	Soil + .6m Clay	Soil + 1m Clay	Soil + Other
Depth of cover (m)	5.1	3.2	1.9	.5
Vol. of pit				
With clay liner (m3)	1,771,000	1,482,000	1,277,000	1,045,000
No clay liner (m3)	1,620,000	1,323,000	1,110,000	872,000
Vol. of clay liner (m3)	151,000	159,000	166,000	173,000
Area for other liner (m2)	153,000	162,000	168,000	175,000
Vol. of clay cap (m3)	-	97,000	169,000	-
Area of other cap (m2)	-	-	-	174,000
---------------------Costs (in thousands of 1978 dollars)-----------------				
Earth work				
No clay liner				
Normal digging	$4,800	$3,920	$3,290	$2,580
Shale	7,180	5,860	4,920	3,860
Clay liner				
Normal digging	5,240	4,390	3,780	3,090
Shale	7,850	6,570	5,660	4,630
Liner				
Clay				
With clay available	310	330	340	360
With clay purchase	760	760	830	870
Other				
Asphalt	270	290	300	310
Synthetic	670	710	740	780
Cap				
Clay				
With clay available	-	200	350	-
With clay purchase	-	490	850	-
Other				
Asphalt	-	-	-	310
Synthetic	-	-	-	770

a conventional mill tailings. Nitrates are quite mobile if seepage reaches ground water. The cost of chemical treatment of tailings is as yet undetermined, but could be expected to be as expensive as the original milling process, excluding ore grinding. Since this technique is expected to be only about 90% effective, some action would still be required to isolate the tailings from the biosphere and to dispose of the extracted material in a licensed waste burial site.

Uranium mill tailings disposal by a nitric acid leaching process requires construction and operation of a nitric acid leaching mill, disposal of the concentrated nitric acid leachate, and disposal of the residual tailings. The construction and operation of a nitric acid leaching mill is quite expensive. The NRC-DGEIS (NR 79) estimates that a model nitric acid leaching mill costs $35 million to construct and an additional $37.7 million to equip (1978 dollars), while operating costs are expected to run $12.50 per ton of processed uranium mill tailings.

Assuming that the model inactive mill pile contains 1.32 million short tons of tailings and that a model nitric acid leaching mill can process 1,984 short tons of mill tailings and produce 55 short tons of nitric acid leachate per day, then 668 days of operation would be required to process the mill tailings. In addition, approximately 37,000 short tons of nitric acid leachate will be generated. Consequently, the total operating cost for a model nitric acid leaching mill at the model inactive mill tailings pile is expected to run $16.6 million. Some of the construction materials used in a model nitric acid leaching mill might be employed at more than one inactive mill tailings site, or might have some scrap value. These possibilities are not analyzed here, due to the uncertainties of apportioning construction costs and determining future scrap values. We therefore assume that each inactive mill tailings site requires building a new nitric acid leaching mill at a cost of $35 million. On the other hand, we assume that the nitric acid leaching equipment can be used at more than one inactive mill tailings site. As a result, cost of the nitric acid leaching equipment is equal to its depreciated value. Assuming two years of use at the model inactive mill tailings site, a 15-year life expectancy for the nitric acid leaching equipment, and straight-line depreciation, the expected cost of the nitric acid leaching equipment is $5 million at each model inactive mill tailings site. An additional $5 million is added to cover the costs of transportation between different mill tailings sites, set-up and take-down costs, and extra wear and tear on the equipment, as well as other contingencies. We therefore expect the total nitric acid leaching equipment costs to be $10 million. In total, we expect nitric acid leaching to cost $61.6 million (1978 dollars) to construct, equip, and operate the model inactive mill tailings site.

When combined in an asphalt or cement matrix, the nitric acid leachate matrix has a volume of 17,100m3 and requires a cover 10m thick for proper disposal. The disposal of the nitric acid leachate would require a pit 13.4m deep and covering an area of .5 hectares (100m by 50m). The possible costs of disposing of the nitric acid leachate are presented in Table B-19.

TABLE B-19

Costs of Nitric Acid Leachate Disposal
(thousands of 1978 dollars)

Task	Cost
Earth work	
Normal digging	$200
Shale	300
Fixation	
Asphalt	560
Cement	380
Stabilization	
Vegetation	
No need to purchase soil	4
With soil purchase	30
Irrigation	2
Riprap	60
Gravel	10
Chemical	4
Fencing(a)	
Chain link	10
Security (prison grade) fence	40
Future costs	
Irrigation	10
Chemical stabilization	30
Chain link fence	2
Security (prison grade) fence	10
Value of land	1

(a) Includes a 20m isolation zone around the disposal pit.

The NRC-DGEIS (NR 79) estimates that the concentration of radium remaining in the residual tailings after nitric acid leaching is at least an order of magnitude greater than background levels. If soil with average radon attenuation properties is available in the area, a 3.8m-thick cover will provide attenuation to 0.1 pCi/m^2-sec. Assuming that the nitric acid leaching process insignificantly alters the quantity of residual tailings, and using the assumptions employed for Option 3 (Section B.3.4 -- New Site, Below Grade, with Liner if Needed), then the disposal costs for the residual tailings can be computed. The costs of disposing of the residual tailings are presented in Table B-20.

In summary, nitric acid leaching of the tailings for the model inactive mill site will cost $61.6 million. Under the best conditions, disposal of the nitric acid leachate can be expected to cost an additional $600,000 (normal soil excavation, stabilization with vegetation--no irrigation required--and isolation with a chain-link fence). Under the worst conditions, disposing of the nitric acid leachate will cost $970,000 (shale excavation, riprap stabilization and security fence isolation). Disposal costs for the residual tailings will be $7 million at best--that is, if no liner is required; excavation is in normal soil; tailings are transported by truck and rail; vegetation requiring no irrigation is used to stabilize the disposal site; and the disposal site is isolated with a chain-link fence. On the other hand, the costs of disposing of the residual tailings could be as high as $13.1 million if a clay liner is used and the clay must be purchased; pit excavation is in shale, trucks are the only transportation available for the tailings; and the disposal site is stabilized by riprap and isolated by a security

TABLE B-20

Costs of Residual Tailings Disposal
(thousands of 1978 dollars)

Task	Cost
Earth work	
Clay liner not required	
Normal digging	$4,200
Shale	6,290
Liner	
Clay	
With clay available	320
With clay purchase	780
Asphalt	280
Synthetic	700
None	--
Tailings excavation, loading, spreading and compacting	1,500
Tailings transportation	
Truck	1,300
Truck and rail	1,100
Pipeline	1,270
Stabilization	
Vegetation	
No need to purchase soil	130
With soil purchase	440
Irrigation equipment	30
Riprap	2,280
Gravel	450
Chemical	130
Fencing	
Chain link	50
Security (prison grade)	160
Future Costs	
Irrigation equipment	100
Chemical stabilization	500
Chain-link fence	10
Security (prison grade) fence	20
Value of land	20

fence. As a result, the cost of uranium mill tailings disposal at the model inactive mill site, using a nitric acid leaching process, could be expected to range between \$69.2 and \$75.7 million.

B.4.2 Long-Term Radon and Hydrology Control

It is unreasonable to expect that the uranium mill tailings can be completely isolated at the existing sites. The concept of complete long-term isolation (of both radon and ground water) essentially requires special site selection and emplacement techniques. The NRC DGEIS (NR 79) describes two methods that conceivably will meet these criteria: deep disposal in an open-pit mine and deep disposal in an underground mine.

In the case of an open-pit mine, the mill tailings may be loosely deposited in the pit but enclosed in a watertight liner and cap, or they can be combined with asphalt or cement to prevent leaching into the surface and ground water environment. Table B-21 presents cost estimates which assume an available open-pit coal mine or copper quarry within 10 miles. Long-term radon and hydrology control could cost as little as \$6.9 million. This includes only expenses for dragline excavation of the tailings, truck and rail tailings transport, and loose tailings disposal with an asphalt liner and cap. These cost estimates are relatively low

TABLE B-21

Cost Estimates for Deep Disposal When a Nearby Open-Pit Mine Is Available

(thousands in 1978 dollars)

Task	Cost
Evacuate & load tailings	$1,200
Tailings transportation	
Truck	1,330
Truck & rail	1,100
Pipeline	1,300
Tailings disposal	
Loose with liner & cap	4,600
Cement fixation	
Thermal evaporator	17,900
Filter bed	10,830
Asphalt fixation	
Thermal evaporator	24,930
Filter bed	17,840
Disposal of mine contents	28,130
Vegetation cover	
No need to purchase soil	690
Soil purchase required	4,600

because it is assumed that there is an operating open-pit mine close to the mill tailings pile, and that the mine owners are willing to cover the mill tailings at no cost as part of their post-operation reclamation of the mine site. On the other hand, costs could increase to $57.5 million, if the mill tailings are deposited in an abandoned open pit mine, transported by truck, dried by a thermal evaporator, and incorporated into an asphalt matrix. It is also assumed that the disposal site is stabilized with vegetation, requiring the purchase of suitable top soil. Unlike the previous control levels, however, there is no long-term commitment to institutional maintenance and the site will be available for alternative future uses.

In another approach, it is assumed that a nearby abandoned underground mine is available. In this case, it is assumed that the tailings will need to be fixed in an asphalt or cement matrix to prevent leaching. Further, holes will be bored into the mine cavities for depositing the asphalt or cement matrix. Cost estimates for deep disposal of the mill tailings in an underground mine are presented in Table B-22. Implementing this method of tailings disposal would cost from $13.1 million to $27.5 million.

TABLE B-22

Cost Estimates of Deep Disposal When a Nearby Underground Mine Is Available

(thousands in 1978 dollars)

Task	Cost
Evacuate & load tailings	$1,200
Tailings transportation	
Truck	1,330
Truck & rail	1,100
Pipeline	1,300
Bore holes	20
Tailings disposal	
Cement fixation	
Thermal evaporator	17,900
Filter bed	10,830
Asphalt fixation	
Thermal evaporator	24,930
Filter bed	17,840

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APPENDIX C

Toxicologies of Toxic Substances in Tailings

APPENDIX C: Toxicologies of Toxic Substances in Tailings

The toxicologies of the following substances found in tailings are summarized:

arsenic
barium
cadmium
chromium
lead
mercury
molybdenum
nitrate
radium
selenium
silver
thorium
uranium

C.1 Arsenic

Arsenic is a metal apparently not essential to human nutrition. It is widely distributed in nature and used estensively in medicine and agriculture. The pentavalent form is less toxic than the trivalent (23 milligrams of arsenic taken as arsenic trioxide has been fatal (JO 63)), but usually more teratogenic(1) (VE 78).

Chronic poisoning produces skin abnormalities, proteinuria, anemia, and swelling of the liver. Some cardiac and nervous symptoms have been associated in Japan with drinking well water containing 1 to 3 parts per million of arsenic (TE 60). Epidemiologic studies of chronic arsenic poisoning in Antofagasta, Chile, found a high incidence of skin and cardiovascular abnormalities; chronic coryza and abdominal pain, and some chronic diarrhea in children who drank water containing 600 to 800 parts per billion of arsenic (NA 77). The incidence of skin lesions decreased by a factor of about 16 when the arsenic content of the water was decreased to 80 parts per billion (NA 77), but the effects did not disappear completely.

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(1) Teratogenicity is the capability to cause abnormal fetal development.

Chronic consumption of arsenic has also been linked with increased incidence of lung cancer (VE 78) and skin cancer (VE 78, NA 77, GO 77).

C.2 Barium

Barium is a metal apparently not essential to human nutrition. It is widely distributed in nature and used in industry, medicine, and agriculture. Consumption of 550 to 600 milligrams of barium as barium chloride has been reported to be fatal (SO 57).

Ingested barium causes abnormal muscle stimulation due to induced release of catacholamines from the adrenal medulla. There is, however, no evidence of chronic toxicity from long-term consumption of barium in people or animals (NA 77, UN 77).

C.3 Cadmium

Cadmium is a metal distributed in the environment in trace quantities except in some zinc, copper and other ores. It is not essential to human nutrition. It is used in industry. Acute fatal poisoning with cadmium is difficult because cadmium salts cause vomiting when consumed. Acute poisoning from consuming food or drink contaminated with cadmium occurs 15 to 30 minutes after 15 to 30 milligrams of cadmium has been swallowed (EN 79). Symptoms include continuous vomiting, salivation, choking sensations, abdominal pain, and diarrhea. Acute toxicity symptoms have been reported in school children eating popsicles containing 13 to 15 milligrams of cadmium per liter (EN 76).

Absorbed cadmium is toxic to all body organs, damaging cells and enzyme systems. Little is excreted, so it accumulates over the lifetime. In Japan, where people consumed about 0.6 milligrams of cadmium per day, chronic toxicity was reported (EN 76). The illness was called "Itai-itai" disease, and resulted in bone and kidney damage. Symptoms were seen mostly in older women whose diets were very poor, especially lacking in protein and calcium (UN 77, NA 77). Since cadmium toxicity is moderated by calcium, zinc, copper and maganese (UN 77) and selenium, iron, vitamin C, and protein (GO 77), diet is important.

The earliest symptom of chronic cadmium toxicity is kidney damage, evidenced by increased protein in the urine. This occurs when the cadmium level in the renal cortex reaches 200 to 300 micrograms per gram of wet weight (EN 76, EN 79). This 200-microgram level can be reached after consuming about 350 micrograms of cadmium a day for 50 years (EN 76). Consumption of only 60 micrograms a day has been estimated to cause kidney damage in 1% of the exposed group (EN 79). The body retains as much cadmium from smoking one pack of cigarettes per day as from ingesting 25 micrograms of cadmium a day (EN 79).

Cadmium has caused reproductive disturbances and teratogenesis in experimental animals fed high levels (VE 78, UN 77, EN 79, NA 77). It has also been implicated in human hypertension, cardiac problems, and prostatic carcinogenesis (UN 77, EN 79, GO 77, NA 77), but the connection is not definitive.

C.4 Chromium

Chromium is a metal that is essential to human nutrition; it is involved in glucose and lipid metabolism and protein synthesis (UN 77). It is widely distributed in nature and has many industrial applications. Oral toxicity is low; humans can tolerate 500 milligrams daily of chromic sesquioxide (VE 78). Hexavalent chromium is more toxic than trivalent (UN 77, VE 78). The principle damage in acute chromium poisoning is tubular necrosis in the kidney. Large enough doses of hexavalent chromium can cause gastrointestinal tract hemorrhaging, but lifetime exposure of laboratory animals to less than 5 parts per million of chromium in drinking water caused no reported effects (NA 77, UN 77).

No information exists on the effects of chronic consumption in humans.

C.5 Lead

Lead is a metal widely distributed in nature and used extensively in industry and agriculture; it is not essential to human nutrition. The amount of lead absorbed before symptoms of toxicity appear is rarely known; however, one man ingested 3.2 milligrams per day for two years before symptoms occurred (NA 72).

Toxicity is usually related to levels of lead in the blood. A level of 330 micrograms per 100 grams of blood has been associated with acute brain pathology and death in children (NA 72). Levels of 80 micrograms per 100 grams of blood and greater have been associated with brain, nervous system, and kidney pathology; severe colic; seizures; paralysis; blindness, and ataxia in children (NA 72, GO 77, NA 77, UN 77). Subclinical (hard to detect because clinical symptoms are lacking) effects on the central nervous system, the red blood cells, the kidneys, and enzymes may occur at levels of 40 to 80 micrograms of lead per 100 grams of blood (GO 77). In women and children some changes in red cells can be detected at 25 to 30 micrograms per 100 grams of blood (NA 77).

Drinking water containing 100 micrograms of lead per liter results in blood lead levels of 25 to 40 micrograms per 100 grams of blood, (UN 77, NA 77). Such exposure could lead to some clinical lead poisoning, particularly in children (NA 77).

C.6 Mercury

Mercury is a metal not essential to human nutrition. It is distributed in nature as a trace element except in some metal ores, and has many industrial applications. Consumption of 158 milligrams of mercury as mercuric iodide has been reported fatal (VE 78). Effects of nonfatal doses of mercury salts include local irritation, coagulation, and necrosis of tissue, kidney damage, colitis, hallucinations, and a metallic taste in the mouth.

As with lead, chronic mercury poisoning develops slowly. Many of the symptoms relate to the nervous system: impaired walking, speech, hearing, vision, or chewing; insomnia; anxiety; mental disturbances; and ataxia. There also may be damage to kidneys, blood cells, gastrointestinal tract, and enzyme systems (NA 77, VE 78). Studies of Minamata disease (methyl mercury poisoning) suggest that consumption of one milligram of mercury per day as methyl mercury over a period of several weeks will be fatal (VE 78); consumption of 0.3 milligrams per day will cause clinical symptoms of mercury poisoning (UN 77, NA 77). About 10 times as much methyl mercury would be absorbed as inorganic mercury (GO 77).

Mercury passes through the placenta. It has caused cases of Minamata disease by fetal exposure (NA 77), and may cause birth defects (VE 78, UN 77).

C.7 Molybdenum

Molybdenum is a metal essential in trace quantities for human nutrition. It is present in nature in trace quantities, except in some ores. It has been widely used in industry. There are no data for acute toxicity of molybdenum in humans following ingestion, but the animal data (VE 78) shows that it must be in the range of hundreds of milligrams per kilogram of body weight.

Chronic toxicity has been seen in persons who have consumed 10 to 15 milligrams of molybdenum per day (CH 79). Clinical signs of the toxicity were a high incidence of a gout-like disease and increased urinary excretion of copper and uric acid. Increased urinary copper excretion has been observed in persons who consumed 0.5 to 1.5 milligrams of molybdenum per day, and in persons who drank water containing 0.15 to 0.20 milligrams of molybdenum per liter, but not in persons who drank water containing up to 0.05 milligrams of molybdenum per liter (CH 79). The significance of the increased copper excretion is not known.

C.8 Nitrate

Nitrate, a salt of nitric acid, is the stable form of combined nitrogen in oxygenated water, and all nitrogenous materials in natural waters tend to be converted to nitrate (NA 77). The fatal dose has been estimated as 120 to 600 milligrams of nitrate (27 to 136 milligrams of nitrate-nitrogen) per kilogram of body weight (BU 61). Burden estimated the maximum permissible dose of nitrate-nitrogen as 12 milligrams in a three-kilogram infant and 240 milligrams in a 60-kilogram adult (BU 61). Apparently nitrate is converted to nitrite in the gastrointestinal tract, and the absorbed nitrite causes the toxicity (NA 72a, NA 77).

Chronic toxicity is usually observed in children. Symptoms of toxicity have been reported in children drinking water with 11 milligrams or more of nitrate-nitrogen per liter, but not in those consuming nine milligrams or less per liter (NA 72a, NA 77).

Nitrates can be reduced to nitrites and combined with secondary amines or amides to form N-nitroso compounds, which are considered carcinogens (NA 72a, NA 77).

C.9 Radium

Radium is a metal widely distributed in the environment in trace quantitities except in some ores. It is not essential to human nutrition. In the past it was widely used in industry and medicine. No reliable data exist on acute radium toxicity in humans (SI 45) and chemical toxicity, if any, is expected to be masked by radiation damage (VE 78).

Chronic intake of radium is expected to be carcinogenic, especially in bone. Radium isotopes are expected to have roughly the same chronic toxicity per unit of activity (picocurie) consumed, but not per unit of weight (microgram) consumed (IN 79). Radium-227, which is one thousand to ten thousand times less toxic than other radium isotopes (IN 79), may be an exception.

Consuming one picocurie of radium per day continuously entails a risk of developing cancer of about one in 10 million per year (EN 76).

C.10 Selenium

Selenium, a metal, is widely but unevenly distributed in nature. It is essential in human nutrition in trace amounts (NA 77). It is used in industry and medicine.

Drinking water containing nine milligrams of selenium per liter for a three month period caused development of symptoms of selenium toxicity: listlessness, loss of hair, and loss of mental alertness (EN 76). Other symptoms of selenium toxicity include garlicky breath, depression, dermatitis, nervousness, gastrointestinal disturbance, and skin discoloration (EN 76, NA 77). Consumption of one milligram per kilogram of body weight per day may cause chronic selenium poisoning (GO 77). Bad teeth, gastrointestinal disturbances and skin discoloration have been associated with consumption of 0.01 to 0.1 milligram of selenium per kilogram of body weight per day (EN 76).

Selenium has also been suggested to cause increased teratogenesis and dental caries, but there are little data on these questions (VE 78).

C.11 Silver

Silver is a metal distributed in trace levels in the environment except in some ores. It is not essential to human nutrition. It is widely used in industry, medicine, photography, and art. Data on acute toxicity in people are sparse, but consumption of 140 milligrams of silver nitrate causes severe gastroenteritis, diarrhea, spasms, and paralysis leading to death (VE 78).

Chronic toxicity from soluble silver salts is usually associated with argyria, a permanent blue-grey discoloration of the skin caused by deposited silver (EN 76, NA 77). Silver deposited in tissue, especially in the skin, apparently is retained there indefinitely (EN 76), perhaps as a harmless silver-protein complex, or as silver sulfide or selenide (VE 78). If one gram of accumulated silver causes borderline argyria, as postulated by the National Academy of Sciences, this level would be reached after 50 years of drinking water containing 50 micrograms of silver per liter, or after 91 years at 30 micrograms per liter (NA 77). Prolonged consumption of silver salts may also cause liver and kidney damage and changes in blood cells (VE 78).

C.12 Thorium

Thorium is a metal distributed in the environment in trace quantities, except in some ores. It is not essential to human nutrition. It is used in industry and as a nuclear power source. It was formly used in medicine.

There are no data on toxicity in humans. In animal studies, thorium given orally at levels near one gram per kilogram of body weight causes death in half of the animals (VE 78).

Chronic toxicity appears limited to carcinogenesis associated with the radioactivity of the thorium. The various isotopes of thorium are expected to vary greatly in toxicity, considered on a per-unit-activity basis (IN 79); all are expected to produce radiation-related cancers.

C.13 Uranium

Uranium is a metal widely distributed in the environment in trace quantities. It is not essential to human nutrition. It is used in the nuclear power industry.

Acute toxicity in humans has been estimated to occur, based on kidney damage, following absorption of 0.1 milligram per kilogram of body weight; some deaths would be expected following absorption of one milligram per kilogram of body weight (LU 58). If 20% of the uranium in water is absorbed, this would be equivalent to 17.5 milligrams and 175 milligrams per liter of uranium, respectively, for a 70-kilogram man. Oral doses of 10.8 milligrams of uranium (as uranyl nitrate hexahydrate) apparently caused no kidney damage (HU 69). However, consumption of 470 milligrams of uranium (one gram of uranyl nitrate) caused vomiting, diarrhea, and some albuminuria (BU 55).

Building up a tolerance to uranium is apparently possible. Spoor cites reports from the medical literature of the 1890's where uranyl nitrate was used to treat diabetes, starting with a conditioning dose of about 60 milligrams of uranyl nitrate three times a day after meals and gradually raising the dose to six grams of uranyl nitrate a day (SP 68). If such doses were given without conditioning, they would be expected to be fatal.

Chronic toxicity may also be related to enzyme poisoning in the kidneys (LU 58), with some liver damage as a result of the kidney damage (VE 78). Experiments with animals which inhaled uranium compounds for a year showed mild kidney changes associated with about one microgram of uranium per gram of kidney. Extending these results to a human kidney weight of 300 grams, absorption of 20% of uranium in water and deposition of 11% of absorbed uranium in the kidney retained with a 15-day half-life (SP 73) could cause chronic chemical toxicity in humans who drink water containing about 315 micrograms of uranium per liter.

Uranium can also cause chronic toxicity in the form of radiation-related carcinogenesis. The various uranium isotopes vary greatly in their carcinogenic potentials as considered on a unit activity basis (IN 79). There is some question as to whether radiation-related cancer or chemical toxicit will be the major response to some uranium isotopes.

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APPENDIX D

The Proposed Standards

The Administrator of the Environmental Protection Agency hereby proposes to add a Part 192 to Title 40 of the Code of Federal Regulations as follows:

Part 192 - ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM MILL TAILINGS

Subpart A -- Environmental Standards for the Disposal of Residual Radioactive Materials from Inactive Uranium Processing Sites

192.01 Applicability
192.02 Definitions
192.03 Standards
192.04 Effective date

Subpart B - Environmental Standards for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability
192.11 Definitions
192.12 Standards
192.13 Effective date

Subpart C -- Exceptions

192.20 Criteria for exceptions

192.21 Remedial actions for exceptional circumstances

(Authority: Section 275 of the Atomic Energy Act of 1954, 42 U.S.C. 2022, as amended by the Uranium Mill Tailings Radiation Control Act of 1978, PL 95-604.)

Subpart A -- Environmental Standards for Disposal of Residual Radioactive Materials from Inactive Uranium Processing Sites

192.01 Applicability

This subpart applies to the disposal of residual radioactive material at any designated processing site or depository site as part of any remedial action conducted under Title I of the Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604), or following any use of subsurface minerals at such a site.

192.02 Definitions

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as in Title I of the Uranium Mill Tailings Radiation Control Act of 1978 and the Atomic Energy Act.

(b) Remedial action means any action performed under Section 108 of the Uranium Mill Tailings Radiation Control Act of 1978.

(c) Disposal means any remedial action intended to assure the long-term, safe, and environmentally sound stabilization of residual radioactive materials.

(d) Disposal site means the region within the smallest practical boundaries around residual radioactive material following completion of disposal.

(e) Depository site means a disposal site selected under Section 104(b) or 105(b) of the Uranium Mill Tailings Radiation Control Act of 1978.

(f) Aquifer means a geologic formation, group of formations, or portion of a formation capable of yielding usable quantities of ground water to wells or springs.

(g) Ground water means water below the land surface in the zone of saturation.

(h) Underground source of drinking water means:

(1) an aquifer supplying drinking water for human consumption, or

(2) an aquifer in which the ground water contains less than 10,000 milligrams/liter total dissolved solids.

(i) Curie (Ci) means the amount of radioactive material which produces 37 billion nuclear transformations per second. One picocurie (pCi) = 10^{-12} Ci.

(j) Surface waters means "waters of the United States, including the territorial seas" ("navigable waters") as defined in the *Federal Register*, Volume 44, page 32901, June 7, 1979. (Comment: This definition is taken from the Regulations for the National Pollutant Discharge Elimination System, 40 CFR 122.3(t). In essence, it includes all U.S. surface waters which the public may traverse, enter, or draw food from.)

192.03 Standards

Disposal of residual radioactive materials shall be conducted in a way that provides a reasonable expectation that for at least one thousand years following disposal --

(a) The average annual release of radon-222 from a disposal site to the atmosphere by residual radioactive materials will not exceed 2 pCi/m^2-sec.*

(b) Substances released from residual radioactive materials after disposal will not cause

(1) the concentration of that substance in any underground source of drinking water to exceed the level specified in Table A, or

(2) an increase in the concentration of that substance in any underground source of drinking water, where the concentration of that substance prior to remedial action exceeds the level specified in Table A for causes other than residual radioactive materials.

This subsection shall apply to the dissolved portion of any substance listed in Table A at any distance greater than 1.0 kilometer from a disposal site that is part of an inactive processing site, or greater than 0.1 kilometer if the disposal site is a depository site.

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* NOTE: The radon emitted from a tailings site after disposal will come from the tailings and from materials covering them. Radon emissions from the covering materials should be estimated as part of developing a disposal plan for each site. These plans will be reviewed and concurred with by the Nuclear Regulatory Commission prior to disposal. After disposal, the radon emission standard is satisfied if the emission rate is less than or equal to 2 pCi/m^2-sec plus the emission rate expected from the disposal materials.

(c) Substances released from the disposal site after disposal will not cause the concentration of any harmful dissolved substance in any surface waters to increase above the level that would otherwise prevail.

192.04 Effective date

The standards of this Subpart shall be effective 60 days after final promulgation of this rule.

Subpart B -- Environmental Standards for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability

This subpart applies to open lands and buildings which are part of any processing site designated by the Secretary of Energy under PL 95-604, Section 102. Section 101 of PL 95-604, states that "processing site" means --

(A) any site, including the mill, containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to any Federal agency prior to January 1, 1971 under a contract with any Federal agency, except in the case of a site at or near Slick Rock, Colorado, unless --

(i) such site was owned or controlled as of January 1, 1978, or is thereafter owned or controlled, by any Federal agency, or

(ii) a license (issued by the (Nuclear Regulatory) Commission or its predecessor agency under the Atomic Energy Act of 1954 or by a State as permitted under section 274 of such Act) for the production at such site of any uranium or thorium product derived from ores is in effect on January 1, 1978, or is issued or renewed after such date; and

(B) any other real property or improvement thereon which --

(i) is in the vicinity of such site, and

(ii) is determined by the Secretary, in consultation with the Commission, to be contaminated with residual radioactive materials derived from such site.

Any ownership or control of an area by a Federal agency which is acquired pursuant to a cooperative agreement under this title shall not be treated as ownership or control by such agency for purposes of subparagraph (A)(i). A license for the production of any uranium product from residual radioactive materials shall not be treated as a license for production from ores within the meaning of subparagraph (A)(ii) if such production is in accordance with section 108(b).

192.11 Definitions

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Uranium Mill Tailings Radiation Control Act of 1978.

(b) Remedial action means any action performed under Section 108 of the Uranium Mill Tailings Radiation Control Act of 1978.

(c) Open land means any surface or subsurface land which is not a disposal site and is not covered by a building.

(d) Working Level (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts.

(e) Dose equivalent means absorbed dose multiplied by appropriate factors to account for differences in biological effectiveness due to the type and energy of the radiation and other factors. The unit of dose equivalent is the "rem."

(f) Curie (Ci) means the amount of radioactive material which produces 37 billion nuclear transformations per second. One picocurie (pCi) = 10^{-12} Ci.

192.12 Standards

Remedial actions shall be conducted so as to provide reasonable assurance that --

(a) The average concentration of radium-226 attributable to residual radioactive material from any designated processing site in any 5 cm thickness of soils or other materials on open land within 1 foot of the surface, or in any 15 cm thickness below 1 foot, shall not exceed 5 pCi/gm.

(b) The levels of radioactivity in any occupied or occupiable building shall not exceed either of the values specified in Table B because of residual radioactive materials from any designated processing site.

(c) The cumulative lifetime radiation dose equivalent to any organ of the body of a maximally exposed individual resulting from the presence of residual radioactive materials or byproduct materials shall not exceed the maximum dose equivalent which could occur from radium-226 and its decay products under paragraphs (a) and (b) of this section.

192.13 Effective date

The standards of this Subpart shall be effective 60 days after promulgation of this rule.

Subpart C -- Exceptions

192.20 Criteria for exceptions

Exceptions to the standards may be justifiable under any of the following circumstances:

(a) Public health or safety would be unavoidably endangered in attempting to meet one or more of the requirements of Subpart A or Subpart B.

(b) The goal of environmental protection would be better served by not satisfying cleanup requirements for open land, Sec. 192.12(a) or the corresponding part of Sec. 192.12(c). To justify an exception to these requirements there should be a clearly unfavorable imbalance between the environmental harm and the environmental and health benefits which would result from implementing the standard. The likelihood and extent of current and future human presence at the site may be considered in evaluating these benefits.

(c) The estimated costs of remedial actions to comply with the cleanup requirements for buildings, Sec 192.12(b) or the corresponding part of Sec. 192.12(c), are unreasonably high relative to the benefits. Factors which may be considered in this judgment include the period of occupancy, the radiation levels in the most frequently occupied areas, and the residual useful lifetime of the building. This criterion can only be used when the values in Table B are only slightly exceeded.

(d) There is no known remedial action to meet one or more of the requirements of Subpart A or Subpart B. Destruction and condemnation of buildings are not considered remedial actions for this purpose.

192.21 Remedial actions for exceptional circumstances

Section 108 of PL 95-604 requires the Secretary of Energy to select and perform remedial actions with the concurrence of the Nuclear Regulatory Commission and the full participation of any State which pays part of the cost, and in consultation, as appropriate, with affected Indian tribes and the Secretary of the Interior. Under exceptional circumstances satisfying one or more of the conditions 192.20(a), (b), (c), and (d), the Department of Energy may select and perform remedial actions, according to the procedures of Sec. 108, which come as close to meeting the standard to which the exception applies as is reasonable under the exceptional circumstances. In doing so, the Department of Energy shall inform any private owners and occupants of affected properties and request their comments on the selected remedial actions. The Department of Energy shall provide any such comments to the parties involved in implementing Sec. 108 of PL 95-604. The Department of Energy shall also inform the Environmental Protection Agency of remedial actions for exceptional circumstances under Subpart C of this rule.

TABLE A

Arsenic	0.05	milligram/liter
Barium	1.0	milligram/liter
Cadmium	0.01	milligram/liter
Chromium	0.05	milligram/liter
Lead	0.05	milligram/liter
Mercury	0.002	milligram/liter
Molybdenum	0.05	milligram/liter
Nitrogen (in nitrate)	10.0	milligram/liter
Selenium	0.01	milligram/liter
Silver	0.05	milligram/liter

Combined radium-226 and radium-228	5.0	pCi/liter
Gross alpha particle activity (including radium-226 but excluding radon and uranium)	15.0	pCi/liter
Uranium	10.0	pCi/liter

TABLE B

Average Annual Indoor Radon Decay Product Concentration (including background)	0.015	WL
Indoor Gamma Radiation (above background)	0.02	milliroentgens/hour